The Effect of Cultivar, Seeding Date, Seeding Rate and Nitrogen Fertility on Oat (*Avena sativa* L.) Yield and Milling Quality

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A thesis submitted to the faculty of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Science.

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BY

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree

of

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TABLE OF CONTENTS

ABSTRACT

The Effect of Cultivar, Seeding date, Seeding rate and Nitrogen fertility on Oat (avena sativa l.) Yield and Milling quality: Dr. Martin Entz, Major Advisor

Evaluating newly released oat cultivars for yield and quality responses at varying seeding dates, seeding rates and nitrogen (N) rates will provide up to date information for Western Canadian producers. AC Assiniboia, AC Medallion, and an unregistered semidwarf line, OT 288, were observed in field experiments conducted at Morden, Winnipeg and Carman in 1998 and 1999 at three seeding dates, (late April/early May, mid May, late May/early June) and three seeding rates (200, 300, and 400 seeds/m^2). Grain yield was not reduced with delayed seeding. Test weight, groat percentage and percent plump kernels were negatively affected by delayed seeding and several seeding date x cultivar interactions were observed. Milling quality of AC Assiniboia was less negatively affected by delayed seeding than other cultivars. OT 288 was the highest yielding cultivar, had the highest kernel number, and harvest index, and the lowest kernel weight in all four site years. OT 288 produced higher tiller and panicle numbers per square meter in all site years. Variations in seeding rates did not affect yield at any location and no seeding rate x cultivar interactions were observed.

AC Assiniboia, AC Medallion, CDC Boyer, OT288, and Triple Crown were evaluated for yield and quality responses to N fertilizer in seven field experiments at various Manitoba locations in 1998 and 1999. Four levels of ammonium nitrate fertilizer (0, 40, 80, and 120 kg/ha) were used at locations with variable levels of soil nitrate-N. Significance of N fertilizer effects was dependent upon soil N fertility levels. Positive

yield responses to increasing N fertilizer were observed only at locations with low levels of residual N.

The optimal level N level for AC Assiniboia, AC Medallion, and Triple Crown was approximately 100 kg N per hectare but was found to be 90 kg N per hectare for CDC Boyer. OT 288 was found to be more responsive to N fertilization than the tall cultivars; with an optimal N level for grain yield of approximately 120 kg N per hectare estimated N supply. Nitrogen x cultivar interactions for yield were observed only at locations with low residual N; AC Medallion and CDC Boyer responded differently to N additions beyond the optimal level. Cultivar effects were significant for grain yield with the semidwarf OT 288 resulting in the highest yield in all locations. Nitrogen fertilizer was inconsistent in its effect on grain quality traits; cultivar choice was the most important determinant of grain quality in all trials. At high levels of soil N, grain test weight was reduced with additional nitrogen. AC Assiniboia maintained consistently high quality across locations and N rates, while Triple Crown performed relatively poorly across locations and N rates, probably due to poor stem rust resistance, prevalent in eastern and central Manitoba. Crop lodging could be minimized through cultivar selection and proper monitoring of soil N levels to minimize excessive N applications.

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LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Western Canada has become one of the world's largest oat (*Avena sativa L.*) producing regions. Very little research has been conducted in Western Canada on oat management with the majority of research having been conducted in the United States. Recommended cultural practices for oat production in Manitoba are based on research conducted on older cultivars, which have lower yield potential and are now susceptible to various diseases. In order to improve oat production in Western Canada and increase returns to the producer, research using currently recommended cultivars on prairie soils is needed. As a large portion of the oat crop is sold for milling purposes, management practices must optimize both yield and milling quality characteristics. This study will address N and seeding management for currently recommended cultivars at several locations across Manitoba.

Early seeding has resulted in increased oat yield and quality however several researchers have documented cultivar x seeding date interactions (Wiggans, 1956; Frey, 1959a; Ciha, 1983; Humphreys et al., 1994a). Optimum seeding rates have been found to vary depending on the cultivar and location (Guitard et al.; 1961, Ciha, 1983; Anderson, 1986b; Rioux et al., 1986; Ahmadi et al., 1988). This can be attributed to the fact that oat can adjust tillering and growth according to plant density, preventing major yield fluctuations around the optimum seeding rate (Grafius, 1956; Jones and Hayes, 1967; Forsberg and Reeves, 1995).

The objectives of this study were to:

1) examine whether currently recommended oat cultivars respond differently to seeding date and seeding rate for yield and milling quality,
2) define a set of characteristics and management practices for high yielding and high quality oat crops in Manitoba,
3) test the hypothesis that increased seeding rates or cultivar choice can improve yield and quality with late seeding.

Several studies have documented N x cultivar interactions for oat grain yield (Frey, 1959b; Brown et al., 1961; Ohm, 1976; Brinkman and Rho, 1984), emphasizing the importance of evaluating new cultivars under varying N fertility. Oat can respond to N fertilization, in terms of plant growth, however crop lodging may limit the utilization of high N rates for grain yield (Brinkman and Rho, 1984). For this reason, suboptimal N fertilization is often used in oat production (Marshall et al., 1987). The amount of N needed for optimum yields and responses to N additions are highly dependent on cultivar, environmental conditions, soil type, and cropping history (Forsberg and Reeves, 1995).

Western Canadian oat breeding programs have incorporated the semidwarf gene Dw6 (Brown et al., 1980) into breeding material and the first semidwarf oat cultivar, AC Ronald, has recently been registered. The development of semidwarf wheat (Triticum aestivum L.) and rice (Oryiza sativa L.) cultivars led to the use of more intensive management practices, contributing to increased yields through improved HI (Chandler, 1969; Ali et al., 1978). Semidwarf oat cultivars have also been found to produce above average yields (Brinkman and Rho, 1984). Research using semidwarf oat and wheat cultivars have found that requirements for high yield may or may not differ from tall cultivars (Meyers et al., 1985; Anderson and McLean, 1989; Makela et al., 1996). It is important for this reason to examine and compare tall and semidwarf oat cultivars for their responses to agronomic practices in order to determine the optimum management practices.

The objectives of this study were to:

1) observe yield and milling quality responses of four newly released tall oat cultivars, and one unreleased semidwarf oat cultivar to N fertilizer additions across a range of locations and soil fertility levels in Manitoba,
2) define a set of characteristics and management practices for high yielding and high quality oat crops in Manitoba,
3) observe whether N additions required to achieve optimum yield would result in any detrimental effects on milling quality.

These objectives were achieved through an extensive examination of the yield, yield components, and physical quality characteristics under a diverse range of Manitoba environments and agronomic practices.

2. LITERATURE REVIEW

2.1. General

In the mid 1950's oat (*Avena sativa* L.) were ranked forth in world cereal production, however declining feed oat demands have reduced oat production (Brouwer and Flood, 1995). Recent interest in oat for its dietary value in human consumption has renewed interest in oat production. Since 1980, there has been rapid growth in milling oat production and processing in western Canada. This growth has been due to a number of market factors including changes to North American transportation subsidies, displacement of oat from the US Midwest and Ontario crop rotations, and an evolving processed food market. For the year 1999/2000 Canada produced 3,640,000 metric tonnes of the world's 23,586,000 metric tonne oat supply, compared to 2,122,000 metric tonnes produced in the United States. Economic factors will likely continue to change, however, the concentration of oat processing on the prairies is expected to continue (Pizzey, 1998). The oat crop has become an important component of the western Canadian farm economy, and Manitoba has become one of the largest oat producers in the world (Baker, 1992).

2.2 Biology

Avena sativa (common oat) is an annual grass commonly used in monoculture, double cropping, companion cropping, or forage production. Oat growth is favored by relatively cool and moist growing conditions and is influenced by environmental factors such as soil physical and chemical conditions and available water, temperature and solar irradiation (Marshall et al., 1992).

The oat growth period, from planting to anthesis, is divided into a vegetative and a reproductive phase. During the vegetative phase, the plant remains short, internodes are not elongated, leaves grow and are initiated and tillers are formed (Ross, 1955). During the reproductive phase, floral initiation and differentiation occurs.

Tillers, or lateral branches, of the oat plant originate in the axils of the leaves between emergence of the third leaf and stem elongation (Bonnett, 1960). Generally, most of the tillers surviving at anthesis will produce an inflorescence or panicle.

The oat inflorescence is a loose open panicle with spikelets arranged on branches arising from the rachis (White, 1995). The main axis of the panicle is a continuation of the main stem and ends in a single spikelet (Bonnett, 1960). The length of the rachis and the number of branches per node control the number of spikelets per panicle. There are generally 5 to 7 nodes from which lateral branches arise, ending in apical spikelets. Secondary branches can grow from primary branches producing spikelets, as can tertiary branches arise from secondary. The most basal branch will produce the greatest number of branches. Therefore, spikelets are most numerous at the basal nodes. There are commonly 20 to 50 spikelets per panicle.

The oat spikelet is made up of two empty glumes on a rachilla, and the florets, which form the caryopsis at maturity. Each spikelet contains one to several florets or groats, which are enclosed within the outer stiff lemma and papery palea or hull. Up to four florets can develop within the spikelet however two to three are most common (Takeda and Frey, 1980). When the lemma and palea of the primary floret envelop most of the secondary floret, the primary floret may fail to develop properly. The secondary floret in this case is called a bosom kernel and the entire floret is called a double oat. In this case, both the primary and secondary groats are poorly developed, which is undesirable. A thin or slim oat is long and slender, containing a thin short groat while a pin oat is also very thin but are shorter than a slim oat.

Blast is a yield reducing mechanism found in oat, which affects the inflorescence. Blast can be described as misshapen, withered and empty white spikelets found especially lower on the panicle but occasionally throughout the panicle (Clifford, 1995). The remainder of the spikelets on the panicle develops normally and is healthy and green. It has been suggested that blasting is cultivar related and the result of environmental stress or shock, however no direct confirmation of its causes has been made. Environmental stresses such as insufficient light, cool and cloudy conditions, extremely warm conditions, or moisture stress during kernel differentiation have also been associated with this disorder (Harder and Haber, 1992).

Economically important diseases of oat in Western Canada include crown rust (*Puccinia coronata*), stem rust (*Puccinia graminis*) and barley yellow dwarf virus. Crown rust is more widespread and perhaps the most damaging oat pathogen, however, stem rust epidemics can also be detrimental (Harder and Haber, 1992).

2.3 Factors Affecting Grain Yield

2.3.1 Pre-anthesis Growth and Development

Three components determine oat grain yield, i.e. the number of panicles per square meter, the number of spikelets per panicle, and the weight and number of kernels per spikelet. Root, leaf, stem and tiller production and growth, control of phasic development and panicle structure and development are pre-anthesis processes affected by dry matter accumulation and partitioning (Brouwer and Flood, 1995). The number of tillers and the panicle structure establish yield potential. Together, they determine the sink size, which is formed during the pre-anthesis development period. Tiller initiation and survival, and panicle differentiation will determine the number of potential kernel sites and therefore yield (Shanahan et al., 1984).

Final grain yield is also a function of total dry matter and HI, which can be affected by genetics and growing season conditions (McMullen et al, 1988). Since yield is a function of total dry matter, plants with more dry matter accumulation would be expected to produce higher grain yields. McMullen et al. (1988) found a significant positive correlation (r= 0.80) between dry matter accumulation per plant and grain yield per plant.

Total dry matter is a function of growth rate and growth duration; therefore either of these factors can affect yield capacity. Growth duration is largely predetermined by environment; therefore improvements in growth rate could effectively be used to improve oat yields. In two years of study of 1200 oat lines, Takeda et al. (1980) found oat growth rates ranging from 0.011 to 0.035 g/day/plant (mean 0.021) and 0.013 to 0.032 g/day/plant (mean 0.022). In these same two years, growth rate was significantly correlated with yield (r=0.81 and r=0.52) respectively, and accounted for 50% of the variation in grain yield. Takeda and Frey (1976) found that growth rate was an important factor in determining yields in several oat lines, with more than 90% of the variation in yield being contributed to growth rate. In a similar study they also found significant correlations (r=0.59 to 0.87) between growth rate and grain yield (Takeda and Frey, 1977).

2.3.2 Tiller Production

The expression of tillering potential in oat is influenced by environmental factors and genotype, and is established prior to panicle development. As production, survival and growth of tillers depend on growing conditions, only a proportion may survive to produce panicles contributing to yield. Older, larger tillers have been found more likely to survive than smaller, younger ones; basal tillers (from the first and second leaves) survived better and were more productive than tillers arising from the third leaf (Wiggans and Frey, 1957). The ability to adjust tiller number is an important mechanism allowing cereals to optimize yield under variable seasonal conditions (Anderson, 1986b). The tillering ability of cereals can be seen as advantageous, as it may be correlated to high yielding ability, or disadvantageous as secondary tillers may produce little grain of poor quality (Smith, 1925).

Several researchers have attempted to quantify the contribution of tillers to yield and the relationship between the two. Anderson's (1986b) study of eight spring wheat cultivars found that tiller production was positively related to grain yield up to 600 tillers/m^2 (R^2=0.45). Other studies have found tillers to provide a modest contribution to yield with the first tiller exerting the strongest effect, contributing 69 to 100 % of grain yield depending on the seeding rate (Mundstock and Galli, 1996). Peltonen-Sainio (1991) developed an oat ideotype for northern growing conditions over a series of variable seasons and concluded that increased tillering would not lead to improved grain yields, as panicle number was not correlated to grain yield, and the number of grains per panicle was correlated.

Seeding date and rate, and photoperiod affect tiller production and productivity. Wiggans and Frey (1957) found that weekly seeding intervals resulted in a significant increase in tillers per plant from the first to the fifth planting date. Later seeding dates resulted in a lower number of productive tillers. Among all cultivars evaluated, there was a significant decrease in tiller numbers with increasing seeding rate. High seeding rates often resulted in fewer tillers which produced panicles than the number of seedlings at initial counts. The Field Crop Production Guide (1998) recommends that higher seeding rates should be used to compensate for reduced tiller numbers when seeding is delayed. In contrast Wiggans and Frey (1957), found that tillers per plant were highest at the lowest seeding rate regardless of the seeding date. Mundstock and Galli (1996) also found tiller numbers were greatest at low seeding densities, regardless of seeding date, and tiller survival occurred only at seeding densities lower than 350 seeds/m^2. Increased seeding rates also resulted in fewer grains per panicle, reducing overall contribution of tillers to final yield. In wheat, Anderson (1986b) found that tiller mortality increased, while tillers and spikes per plant decreased with increased seeding rate. However, grain yield was not positively correlated to tiller mortality, therefore, tiller mortality was not a dominant influence on grain yield.

Cultivar effects can significantly impact tiller numbers (Anderson, 1986b, Wiggans and Frey, 1957). Tiller number ranged from 1.6 to 9.3 per plant at the optimum seeding rate for a number of wheat cultivars evaluated and spike number ranged from 1.3

to 10.8 per plant (Anderson, 1986b). Wiggans and Frey (1957) found tillering capacity of several oat cultivars varied, but was constant from year to year.

Environmental factors including N fertility and moisture availability can impact tiller production and contribution to grain yield. Peltonen-Sainio (1997) found that in a favorable year, tillers contributed 13-23% to groat yield, while under poor post-anthesis conditions, tillers senesced and only contributed 6% to final yield. Tillering ability was relatively unimportant to the yield of several barley (*Hordeum vulgare*), wheat, and oat cultivars in a dry year, while in seasons of sufficient rainfall, increased tillering resulted in higher yields (Smith, 1925). Makela et al. (1996) evaluated a range of oat cultivars at N fertilizer rates of 0, 80 and 120 kg/ha. Nitrogen did not affect the number of panicle bearing tillers or the number of tillers per main shoot, and therefore did not significantly affect tiller contribution to grain yield. Over a range of N and seeding rate treatments, Peltonen-Sainio (1997) also found a non significant effect of N on the number of tillers per main shoot. In general, Peltonen-Sainio (1997) reported less than one seed bearing tiller per main shoot regardless of N fertility.

2.3.3 Kernel Number

Maximum kernel number is established during the process of floral initiation during which the apical meristem differentiates. Genotype and environmental conditions will affect the number of potential kernel sites.

In many cereals, kernel number is positively correlated with seed yield. Kernel number is correlated with oat grain yield (McKee et al., 1979; Bloethe and Frey, 1978; Bregitzer et al., 1987). Shanahan et al. (1984) found winter wheat yield to be more consistently correlated to kernel number than kernel weight, suggesting yield was sink, rather than, source limited. Bloethe and Frey (1978) found that an increased number of spikelets per panicle and increased kernel weight were responsible for increased yield in a high yielding oat line. McKee et al. (1979) found that oat grain yield was significantly correlated to length of the grain filling period which was significantly correlated to number of kernels per panicle. Bregitzer et al. (1987) found increases of 15.7% in the number of kernels per panicle resulted in increased grain yield. Panicle population, and therefore the potential kernel number, explained the high yield of the oat cultivar 'Almas' (Rioux et al., 1986). In wheat, spike size and seed size were not clearly related to grain yield, causing Anderson (1986b) to suggest that the culm number leading to a larger number of kernels per area was the source for larger grain yield. Gooding and Lafever (1991) found oat yield reductions with delayed seeding were attributed to a reduction in kernels per panicle and panicle population density.

Genotype can influence kernel production. Semidwarf wheat cultivars were found to develop more florets and kernels per spikelet than tall cultivars, contributing to high yield (Ali et al., 1969). Anderson and McLean (1989) found the semidwarf oat 'Echidna' produced higher yields than the tall cultivars due to the production of a greater number of panicles and kernels per square meter. The oat cultivar 'Andrew' produced relatively higher grain yields than 'Sauk' and 'Bonham', at later seeding dates due to the fact that 'Andrew' developed more kernels per panicle (Frey, 1959a). In this same study, panicle production was positively related to grain yield as were kernels/m^2.

In oat, the number of kernels set per floret is variable and dependent on environment and management (Takeda and Frey, 1980). Increases in tertiary kernel set could be used to increase sink size and therefore yield, if sink size is a limiting factor.

Late sowing reduced percent secondary and tertiary kernel set, while primary kernel set was found to be tolerant of the high temperature conditions typically found with late seeding (Takeda and Frey, 1980). Anderson and McLean (1989) found that changes in seeding rates could not be used to increase kernel numbers, in a tall and two semidwarf oat cultivars.

When oat cultivars respond to N fertilization, it is often associated with a higher number of panicles per plant and the number of kernels per panicle. Frey (1959b) found that although N fertilization reduced kernel weight slightly, it increased the number of kernels per panicle 30, 45, and 50% and panicles per plant 14, 18, and 18% with N additions of 24, 48, and 96 kg/ha N, respectively. Ohm (1976), and Brinkman and Rho (1984) also found that N addition resulted in an increased number of panicles per plant and kernels per panicle. Welch and Yong (1980) attributed large yield increases with N fertilization, entirely to increases in the number of kernels per panicle. Ahmadi et al. (1988) also found that yield increases with N fertilization increased the number of kernels per panicle, suggesting that oat yield was sink limited.

2.3.4 Kernel Weight

Kernel weight is determined during the grain-filling phase of oat development; it will be determined by the ability of the plant to produce photosynthate, leaf area, the length of the grain filling period, and the number of sites or sinks established. In a seeding rate trial conducted in Alberta (Guitard et al., 1961), kernels weights for three oat cultivars ranged from 30.6 to 33.2 g per 1000 kernels averaged over locations, and from 29.0 to 34.9 g per 1000 kernels averaged for each cultivar. Brinkman and Rho (1984) observed weights per kernel ranging from 24 to 33 mg in a cultivar x N trial.

Kernel weight can be affected by genotype. For example, Gooding and Lafever (1991) evaluated three oat cultivars and found that the cultivar 'Heritage' resulted in consistently lower kernel weights than 'Ogle' or 'Porter'. Frey (1959a) found that although 'Andrew' was the highest yielding cultivar in a seeding date trial, it had either the lowest or next to lowest kernel weights at all seeding dates. Anderson and Maclean (1989) found that the semidwarf 'Echidna' resulted in lower kernel weights than the tall cultivar 'Mortlock', although 'Echidna' was consistently higher yielding. In a study by Brinkman and Rho (1984), 'Stout' was the highest yielding cultivar and yield superiority was attributed to an increased number of kernels per panicle and an increased kernel weight. 'Stout's' yield superiority with increasing N fertility was also associated with only small reductions in kernel weight with increasing kernel number, while other cultivars had considerably larger decreases in kernel weight with increased N. High yielding lines derived through breeding had more spikelets per panicle, and increased kernel weight of 12 to15% (Bloethe and Frey, 1978).

Management practices, which alter the grain filling period, can affect kernel weight. Cisar and Shands (1978) and Gooding and Lafever (1991) found that delayed seeding shortened the pre-anthesis, vegetative phase, causing earlier floral initiation. These seeding delays resulted in less favorable conditions during grain filling, i.e. extremely high temperatures, reducing kernel weight. Frey (1959a) also found that delayed seeding significantly reduced kernel weight. In Australia, Anderson and Maclean (1989) found no consistent effect of delayed seeding on kernel weight.

Studies on the impact of seeding rate on kernel weight have shown varying results. Kernel weight was not consistently affected by increasing seeding rates in a semidwarf and two tall oat cultivars (Anderson and Maclean, 1989). Ahmadi et al. (1988) also found no significant effect of increasing seeding rate on kernel weight; grain yield increases at the optimum seeding rates were due to an increased number of grains per panicle and panicle density. Guitard et al. (1961), in Alberta, evaluated three oat cultivars at six seeding rates and observed no influence on kernel weight although a similar evaluation of wheat cultivars resulted in a slight decrease in kernel weight. This illustrates that oat kernel weights may respond differently than wheat, to alterations in seeding rate. Anderson (1986b), working with wheat, examined seeding rates from 50 to 800 seeds per square meter and found that at the optimum seeding rate for each cultivar, grain yield was not correlated to the optimum seeding rate for kernel weight.

Nitrogen fertility has been found to have varying effects on kernel weight. In Australia, Anderson and Maclean (1989) evaluated five N levels ranging from 0 to 120 kg/ha with no consistent effect on kernel weight. Frey (1959b) found that increased N fertilization reduced kernel weight slightly, however the decrease was not significant (2-4%). They concluded that since seed size is established during the period 60 days after planting to maturity, it was relatively unaffected by N fertility. Ahmadi et al. (1988) observed that yield responses due to N fertilization resulted from an increased number of grains per panicle, as there was no effect of timing of N application on kernel weight.

2.3.5 Harvest Index

Harvest index (HI) is defined as the ratio of grain yield to total above ground dry matter, and expresses the efficiency of conversion of photosynthate to grain yield. Adjustments to HI can lead to changes in yield capacity. Harvest index has been found to be positively associated with grain yield increases in oat (Takeda et al., 1980, and

McMullen et al., 1988). In agronomic studies of oat, Salman and Brinkman (1992) observed the highest HI at 54%, while McMullen et al. (1988) observed a maximum of 46%, and a range of 38 to 53% was observed by Brinkman and Rho (1984). In Finland, however, Peltonen-Sainio (1991) found the optimum HI for grain yield occurred at 55% and a HI as high as 60% was recorded.

A number of studies (Takeda et al., 1980, and McMullen et al. 1988) have attributed variation in grain yield to increased growth rate and HI. Takeda et al. (1980) observed that growth rate increases of 0.0003 g/day/plant increased grain yield by 14% while a 5% increase in HI led to a 18-19% increase in grain yield. Bloethe and Frey (1978) however, found that a high yielding oat cultivar showed no differences in HI from the lower yielding cultivars. McKee et al. (1979) found that although cultivars differed in HI, it was not significantly correlated to grain yield. In the latter study, one of the highest yielding cultivars had one of the lowest harvest indexes. In a study by Bregitzer et al. (1987), grain yield and total dry matter were increased through selection 13.5% and 15.9%, respectively, but HI was not affected. Increased HI was also not the cause of a yield increase in the semidwarf 'OT 257', as the HI was similar to that of the tall lower yielding cultivars (Bulman et al.). This suggests that oat yield may be limited by total dry matter production and not the conversion of dry matter into grain yield.

2.3.6 Lodging

Lodging in oat can negatively affect yield and quality through the disruption of the grain filling process. Lodging also makes harvest operations difficult. Weak straw, tall straw, high rainfall, windstorms, and high or unbalanced soil fertility can affect crop lodging (Pendleton, 1954). Few studies have attempted to measure the direct effects of lodging on yield and quality. Pendleton (1954) harvested lodged and unlodged oat and found the latter to be consistently higher yielding. Plots lodged 90 degrees at 4 and 20 days after heading resulted in yield losses of 37 and 14%, respectively. Plots lodged to 45 degrees at the same times had only 17 and 3% yield losses, respectively. Test weight, a measure of grain quality, was also reduced with lodging. A similar study by Norden and Frey (1959) found 90 degree lodging at the early and late stages of grain filling, to result in 36 and 23% yield losses, while 45 degree lodging resulted in 26 and 28% losses. Thirteen percent reductions in test weight were seen with 90 degree lodging and 6% for 45 degree lodging. The authors stated that reduction in grain filling processes caused these losses and harvesting losses would account for additional yield loss.

Lodging evaluations can be complicated by a type of lodging called "stem-break" (Grafius et al., 1955). Stem-break is associated with the processes, which occur during senescence in oat, and occurs when the crop is left to stand in the field after maturity has been reached. A study by Grafius et al. (1955) found that cultivars resistant to lodging were also found to be resistant to stem break.

2.4 Agronomic Management in Oat

Oat is considered the most versatile of cereals and is suited to almost any soil type as long as moisture and temperature are suitable (Sorrells and Simmons, 1992). Because oat has traditionally been regarded as a less management responsive crop, crops often receive lower amounts of fertilizer and are grown on less productive soils than other cereals, causing yields below their genetic potential (Meyers et al., 1985). Through improved management practices, oat yields could be improved without great cost to the farmer. If research can increase returns to the farmer by $10 per acre, there is the potential to add millions of dollars to the farm economy of western Canada (May and Mohr, 1998).

2.4.1 Nitrogen Interactions

Efficient N fertilizer use is a vital component to profitable crop production and sustainable agriculture in Western Canada, as N is the most frequently limiting nutrient in crop production (Tisdale et al., 1993). Nutrient shortages in oat, in the first half of the growing season will lead to plants which are less vigorous with smaller leaves and panicles, and less developed root systems (Forsberg and Reeves, 1995). Nutrient deficiencies later in the season will negatively affect seed set and grain filling (Forsberg and Reeves, 1995). Oat produces enhanced vegetative growth, more tillers, and higher grain yield with N fertilization, if unconstrained by lodging (Sorrell and Simmons, 1992). Yield increases normally result from N additions at the boot stage or earlier, while applications beyond booting will only result in increases in grain protein (Welch and Yong, 1980). A rule of thumb often used in the north central US is that 4.2 kg of available soil N is needed for each 100 kg/ha of harvested grain; a yield of 3225 kg/ha would require 133 kg/ha available N (Forsberg and Reeves, 1995). Proper fertilization management will depend on the previous crop, soil moisture, seasonal rainfall distribution, existing soil nutrient level, yield goal, cultivar used, time of application, and lodging susceptibility (Forsberg and Reeves, 1995).

Indigenous soil nitrate is a source of available N to crops and must be considered when making fertilizer recommendations (Soper et al., 1971). Soil nitrate levels in Manitoba, have increased over the past 25 years due to dramatic increases in N fertilizer use, illustrating that soil nitrate is an important consideration (Guide to soil fertility and fertilizer use in Manitoba, 1993). Initial soil nitrate content and the amount of added fertilizer N influence the recovery of N applied (Peterson and Attoe, 1965). Soper et al. (1971) found highly significant correlations in barley, between nitrate N in the soil at seeding, uptake of N by the above ground portions, and grain yield. Sampling to 61 cm to determine initial nitrate levels can be used to predict N uptake by the crop. In Saskatchewan, Cook et al. (1957) found that positive responses to N fertilizer occurred on continuously cropped fields with less than 50 ppm nitrate accumulation in the top 15 cm, and in fallowed fields with less than 40 ppm nitrate accumulation.

Several studies have documented N x oat cultivar interactions (Brinkman and Rho, 1984, Brown et al., 1961, Frey, 1959b, Ohm, 1976), emphasizing the importance of evaluating new oat cultivars at varying N rates. Frey (1959b) found that grain yield increased approximately 50% relative to an unfertilized check when 22.5 or 45 kg/ha N were added and 65% with a 90 kg/ha application. Fertilization increased the number of panicles per plant and seeds per panicle. Cultivars included in the study responded differently to N, however the highest yielding cultivar, also displayed a strong response in the number of panicles per plant and seeds per panicle to N, indicating that yield was associated with sink size. At the 22.5 kg N/ha level, yield increases were attributed to the production of more panicles per plant, while at the 45 and 90 kg N/ha rate, yield increases were attributed to more seeds per panicle (Frey, 1959b).

Ohm (1976), working in Indiana, found large cultivar x N interactions for oat yield. Twenty of the 21 oat cultivars included in the study demonstrated a wide range of yield increases with the addition of 110 kg N/ha. The cultivar 'Diana', one of the highest yielding cultivars at low N levels, had no response to added N. On the other hand, the highest yielding cultivar at low N levels ('Noble', of similar height), was also the highest yielding at high N levels. Differential cultivar response for grain protein concentration was also observed. For example, the cultivar 'Diana' showed an increase in protein with added N while yield was unaffected by additional fertilizer. The cultivar 'Noble', on the other hand, showed N responses for both percent protein and yield.

Yield increases due to N have mainly been attributed to an increased number of productive panicles per unit area and an increase in the number of seeds per panicle (Brinkman and Rho, 1984; Frey, 1959b; Ohm, 1976). Brinkman and Rho (1984) found the cultivar 'Stout' achieved the greatest yields at higher N rates because of a favorable response for seeds per panicle, a pre-anthesis effect, as well as weight per kernel, and dry matter accumulation after heading, both post-anthesis effects. 'Lodi' and 'Marathon', the other cultivars evaluated, had a more negative post-anthesis response to added N with considerably larger reductions in kernel weight. The range most favorable for this response was between 28 to 84 kg fertilizer N/ha. At the highest rate of N in this study, 112 kg/ha, all cultivars lodged severely. As straw yields increased at the higher N levels, grain yields decreased leading to a reduction in HI.

Working with spring wheat, Gehl et al. (1990) found that the quantity of fertilizer N required to produce maximum grain yield varied with cultivar, site and year. N responses and HI of a particular crop was predominantly influenced by available moisture. 'Solar' and 'Marshall', both semidwarf cultivars, required more N to achieve maximum grain yield than the remaining four cultivars, including two semidwarfs 'Len' and 'HY320'. Differences among cultivars for N response were most evident under high yield potential conditions.

Lamb and Salter (1937) found that although oat cultivars differed in their yielding ability in response to N, the interaction between N level and season was far more significant than the cultivar x N interaction. Suggested in the study was the following concept: oat require a cool, moist environment for optimum development, thus cool weather before heading allows the expression of fertility responses, while hot weather after heading will inhibit the expression of differential responses between cultivars.

Brown et al. (1961) found significant cultivar x N interactions on low, medium, and high fertility soils. The greatest increase in grain, straw and height occurred between the low to intermediate fertilizer treatments. Increase in grain yield with increasing fertility was affected partially by the number of tillers per unit area. High rates of N applied to a low yielding variety resulted in a loss of income while a high yielding variety, at all fertility levels, resulted in a greater income than the low yielding at the highest fertility level. The authors concluded that the inherent ability of a cultivar to produce high grain yields is not expressed at low fertility levels as the highest yielding cultivars were superior at the medium to high N rates.

Considering the variability in cultivar responses to N fertility, it is evident that fertilizer recommendations must be made using research performed on currently recommended cultivars and under conditions typical to the target growing area. Therefore, as new oat cultivars are developed, their N response should be tested against that of established cultivars. Also, it is difficult to consider the effects of N fertilization in isolation. In addition to being influenced by cultivar type, the amount of N needed for optimum grain yields and the response to N additions is highly dependent on climatic conditions, soil type, and cropping history (Forsberg and Reeves, 1995).

2.4.2 Seeding Date Interactions

In Northern temperate zones, maximum grain yield and test weight are usually achieved when oat is seeded early spring. Early seeding results in efficient use of available moisture, avoidance of midsummer drought and heat, and escape from disease epidemics such as crown and stem rust (Forsberg and Reeves, 1995). Several studies have documented the negative effects of delayed seeding and seeding date x cultivar interactions. Evaluation of new cultivars under various seeding dates will allow producers to take advantage of favorable interactions for grain yield.

Faster development rates, with late planting, are known to occur due to photoperiodic response, reducing the length of time in the vegetative and reproductive phases, thus reducing yield (Cisar and Shands, 1978). Wiggans (1956) found that, although cultivars varied in heat unit requirements to reach maturity, the number of calendar days from seeding to maturity decreased rapidly with late seeding and yield declined. Similarly, Colville and Frey (1986), Ross, (1955), and Stoskopf et al. (1966) found the number of calendar days to reach each stage of development was significantly reduced with delayed seeding, shortening the photosynthesis period, reducing carbohydrate production and grain yield. Gooding and Lafever (1991) observed that growth duration decreased by 23 and 25% in two seasons with late seeding, reducing yields by an average of 41% and 24%, respectively. Schmidt (1960) found that the number of days from planting to maturity decreased with delayed seeding. N fertilizer applications at all seeding dates did not significantly affect heading and ripening dates.

Both Gooding and Lafever (1991) and Colville and Frey (1986) found delayed seeding to shorten the vegetative growth stage proportionally more than the grain filling period.

Delayed seeding has been found to have varying affects on oat maturity. Nass et al. (1975) found late seeding (early June) of wheat, barley, and oat resulted in yield reductions along with delayed maturity. Maturity was delayed 7 to 15 days in one year and over 30 days in the second year, with early June seeding. Cisar and Shands (1978) determined that delayed planting hastened maturity of all five cultivars evaluated by shortening the vegetative phase, hastening primordium addition and decreasing the number of primordia formed.

Colville and Frey (1986) evaluated growth duration and development rates in six oat cultivars at seeding dates between mid March and late April in Indiana. In the two years, growing degree days (GDD) and the number of days to reach flag-leaf, heading and 80% panicle ripeness differed significantly, indicating that temperature was not the sole environmental factor affecting development. For example, GDD to reach 80% panicle ripeness in 1981 was approximately 2100 with April 15 and 29 seeding dates and was less than 1900 using the same dates in 1982. In 1981, GDD to reach all seven stages of development generally decreased between March 18 and April 2 seeding dates, however no trend was apparent from April 2 to April 17 and 30 seeding dates. In 1982, the April 28 seeding date had the greatest GDD requirement to any stage of development except the 80% panicle ripeness stage. Wiggans (1956) found that late seeding reduced the number of heat units required for each cultivar to reach maturity. The cultivar 'Marion' required 2350 heat units at early April seeding versus 2095 with late May seeding.

Delaying critical development periods with late seeding can result in less favorable conditions during critical yield development phases depending on the environment. Gooding and Lafever (1991) found that with late seeding, anthesis, seed set, and grain fill took place under less favorable conditions mainly due to high temperatures. This resulted in an overall lower number of seeds and lower kernel weight. High air temperatures (24 °C) also substantially reduced grain yield (Fulton, 1968), by reducing the time between emergence and heading and shortening the grain filling period.

Wiggans (1956) attributed yield loss with later seeding to increased leaf disease. Diseases such as crown and stem rust have a longer time to flourish under their optimum growing conditions, causing greater reductions in yield. Nass et al. (1975) also found that as seeding was delayed, disease severity increased (leaf blotch, *Leptosphaeria avenaria*) and large grain yield reductions occurred.

Significant cultivar x seeding date and cultivar x seeding date x year response for oat grain yield were observed by Ciha (1983), over early, normal, and late seeding dates. Averaged over four years, grain yield and test weight were significantly reduced when seeding occurred after the recommended date (mid April), however some cultivars displayed yield reductions when seeded just past the early seeding date, indicating a cultivar x seeding date interaction. The common practice of increasing seeding rate to compensate for yield loss due to later seeding did not work in this study as no significant cultivar x seeding date x seeding rate interactions were observed. Humphreys et al. (1994a) observed significant cultivar x seeding date interactions for yield; late seeding reduced grain yield in four environments studied, but the extent of yield loss varied with cultivar. The cultivar 'Manic' was not significantly lower yielding than the highest yielding cultivar 'Newman' at the early seeding date, however it was the lowest yielding cultivar with late seeding. Yield component analysis for this study was not available. Later seeding was likely to reduce profitability of the crop due to lower yields, however milling quality did or did not suffer with late seeding depending on the cultivar and growing environment.

Anderson and Hennig (1964) conducted one of the only western Canadian studies of seeding date and fertility level on the yield of 'Beaver' oat. They found that the trend of decreasing yield with a later seeding date could be lessened with the application of 16 kg/ha 11-48-0 fertilizer.

2.4.3 Seeding Rate Interactions

A single optimum seeding rate seldom occurs for oat, since oat plants adjust tillering and growth according to plant density (Forsberg and Reeves, 1995). Small reductions in seeding rate will not result in large yield losses, due to more vigorous plants being produced with more tillers. High seeding rates, however, can result in increased competition, weaker culms, and increased lodging. The Field Guide for Crop Production suggests a seeding rate of 1.5 to 3 bu/acre for oat (Field Crop Production Guide, 1998) however a review of the literature suggests that optimum seeding rates vary depending on the cultivar and the location (Guitard et al., 1961, Ciha, 1983).

Grafius (1956) found that the relationship between stand and number of panicles per unit area was similar to that between seeding rate and yield; increased tillering contributed to grain yield at the low seeding rate but few of the secondary tillers developed panicles at the medium to high rates. In general, wide variations in seeding rates around the optimum produced minor variations in yield. Most of the cultivars evaluated adjusted readily for differences in stand by increasing the numbers of panicles per plant. Of the 40 cultivars evaluated, a seeding rate x cultivar interaction was observed; variations in seeding rate around the optimum for 'Branch' and 'Clintland' resulted in noticeable variations in grain yield.

Over a three year experiment, wide variations in seeding rate (77, 153, 231 kg/hectare) did not have a marked effect on grain yield (Jones and Hayes, 1967). Yield remained largely constant due to the compensatory effects of the various yield components on one another in response to seeding rate. Grain yield seemed to be more variable with season than with seeding rate as was weight per spikelet. Anderson (1986b) studied the relationships between plant population, yield components and grain yield of wheat. The optimum plant population for wheat yields varied depending on the season and cultivar from 30-220 plants/ m^2. At optimum seeding rates grain yield was positively correlated to the number of culms/m^2 up to 600 culms/m^2.

Increased seeding rate generally produced a significant increase in number of panicles per unit area and a decrease in the number of spikelets per panicle and weight per panicle (Jones and Hayes, 1967). Panicle numbers generally increased with an increase in seeding rate while the number of seeds per panicle decreased. Greater panicle number was the major yield component responsible for the yield increase at the optimum seeding rates in a study by Ahmadi et al. (1988). Guitard et al. (1961) found a decrease in kernels per panicle with an increase in oat seeding rate beyond an optimum level. Rates were in the range of 57.2 to 152.4 kg/ha. Yields increased with increased seeding rate up to the optimum of 95.3 kg/ha and were attributed to an increase in the number of plants per acre. Beyond this optimum rate, yields were maintained but as plants per acre increased the number of fertile panicles per plant decreased, rendering the additional seed cost an unnecessary expense. The decrease in kernels per panicle may be attributed to blasting of the kernels occurring in heavy oat stands.

Predicting the optimum seeding rate is difficult due to complications of cultivar interactions and environment. Ciha (1983) found a significant cultivar x seeding rate x year interaction for grain yield. Averaged over years, 'Cayuse' oat, one of three cultivars, had a significant yield increase when seeding rate was increased from 40 to 75kg/ha. The remaining cultivars did not exhibit yield responses to increased seeding rates. When averaged over years, increasing the seeding rate from 75 to 110 kg/ha reduced grain yield in two out of three cultivars, and was attributed to increased lodging. Increasing seeding rate with a later seeding date did not change grain yield or test weight. Ahmadi et al. (1988) found a significant seeding rate x location interaction. Optimum seeding rates were found to be 144 and 108 kg/ha depending on the location. These rates were higher than those previously reported, 90.5 and 75.4 kg/ha (Ciha, 1983; Guitard et al., 1961). Rioux et al. (1986) also found that early seeding was essential for high yield, however, seeding rates varied depending on the location.

2.5 Semidwarf Cultivars and Grain Yield

Lodging is a major factor limiting oat yield increases at higher fertility levels; semidwarf oat could offer a more favorable balance between straw and grain resulting in less lodging (Brinkman and Rho, 1984). Commercial spring oat cultivars in Canada can reach up to 120 cm in height, often increasing susceptibility to lodging. The development of semidwarf wheat (*Triticum aestivum L.*), and rice (*Oryza sativa L.*) cultivars has facilitated the use of more intensive management practices which have contributed to improved grain yields (Chandler, 1969).

The dwarfing gene, Dw6, has been incorporated into breeding material at the Cereal Research Centre in Winnipeg, Manitoba. Dw6 originated from an irradiation process conducted in 1970 in Austria by Brown et al. (1980). The oat line OT 184 was irradiated with 1,150 rads of fast neutrons and the line 'OT 207' a vigorous semidwarf was selected from the derived plant material. Reduced height of the semidwarf was attributed to reduced internode length (up to 40%) beneath the panicle. One major obstacle associated with semidwarf oat lines is incomplete panicle emergence from the leaf sheath. Although there has been less research and breeding for oat compared with wheat and rice, it seems logical to expect higher yielding semidwarf lines to be made available in the near future. Generalizations on the growth characteristics of semidwarf oat cultivars are difficult to make, as results from field studies vary.

Improved yields with semidwarf cereals have been the result of increased HI (Ali et al. 1978). Higher grain yield and responses to applied N, in semidwarf spring wheat cultivars, were explained by higher HI and smaller reductions in HI with incremental fertilization. In contrast with shortened wheat and barley cultivars, Meyers et al. (1985) found that HI of dwarf oat lines was similar to the conventional height lines. In Australia Anderson and Maclean (1989) found that the semidwarf 'Echidna' resulted in higher yields and a higher HI than the tall cultivars 'Mortlock' and 'West'; HI's were 38, 29, and 25% respectively.

It has been suggested that the major value of semidwarf oat lines will be in their protection of yield through lodging resistance rather than superior yield development in response to intensive management practices (Marshall et al., 1987). Meyers et al. (1985) studied the agronomic performance of several semidwarf and tall oat genotypes at high N fertility levels. Their results did not agree with the previous statement by Marshall et al.(1987); grain yields did not differ significantly between genotypes although the tall cultivars displayed lodging while the semidwarf did not. Brown et al. (1980) also recorded less lodging of the semidwarf 'OT 207' compared to the tall cultivars 'Rodney' and 'Hudson', however yields of 'OT 207' were comparable to the tall cultivars. Marshall et al. (1987) studied a tall and a semidwarf oat cultivar and found the tall cultivar, 'Ogle', out-yielded the semidwarf, 'Penlo', even though lodging was observed in 'Ogle' and not in 'Penlo'. Makela et al. (1996) found that a dwarf line yielded less than semidwarf, intermediate, and tall cultivars but out-yielded the tall, lodging sensitive cultivar with a high seeding rate and N; this effect was especially evident in a cool rainy summer favoring stem elongation. Semidwarf wheat cultivars have been found to demonstrate superior grain yield responses under high yielding conditions, due to superior lodging resistance (Dubetz and Bole, 1973). Gehl et al. (1990) found the semidwarf wheat cultivar, 'HY320', to produce the highest grain yield averaged across all treatments. Greater yield stability of the two American semidwarfs tested in high yielding environments, was the result of greater lodging resistance.

It is important to evaluate new semidwarf oat lines under various management practices, as requirements for high yield may or may not differ from tall cultivars. In Australia, dwarf oat has generally out yielded taller types. Anderson and McLean (1989) found that maximum grain yields of the semidwarfs were achieved from various cultivar and management practice combinations rather than individual inputs alone. The largest yield increase with 'Echidna' resulted from combinations of early sowing with a N application and a heavier seeding rate. In Finland, Makela et al. (1996) found the highest yields of the dwarf and semidwarf cultivars were found under typical Finish seeding rates of 500 seeds/m^2. Grain yields of a tall and semidwarf oat cultivar increased when N was increased from 67 to 134 kg/ha with no significant difference in yield response (Marshall et al., 1987). This was contrary to the findings of Anderson and McLean (1989) where the semidwarf had an increased responsiveness to N fertilizer.

Studies in different parts of the world have found yield components in semidwarf oat cultivars to be both similar and superior to tall oat cultivars. Anderson and Maclean (1989) attributed low yields of the dwarf cultivar to a low number of kernels per main shoot panicle however, the dwarf was better able to tiller and produce panicle-bearing tillers than the other cultivars. Increased tillering in the dwarf cultivar could not compensate for the reduced yield potential of the main shoot panicle. Meyers et al. (1985) found kernel number per panicle, kernel weights, and panicle number were similar among the tall and semidwarf genotypes as were grain yields.

Oat straw is commonly used as bedding or sold for industrial use and is therefore of economic importance. Although semidwarf cultivars are shorter in stature, there seems to be no significant reduction in straw production (Bulman et al.). No significant differences in terms of straw and total residue production were found even though the semidwarf 'OT 257' was almost 30 cm shorter than the tall cultivars. Total culm weight of 'OT 257' was similar to taller cultivars, indicating shorter but thicker straw. This same study also found no significant differences in panicle production between the short and tall cultivars. Yield increases of 15% over the tall cultivar were attributed to the lodging resistance of 'OT 257'.

2.6 Oat Quality

Oat is extremely nutritious, high in protein and soluble dietary fiber. Oat bran has been linked to lower blood cholesterol levels and whole oat can improve glucose metabolism (Hurt et al.,1988, Anderson, 1986a). Increases in oat food demands have been attributed to these health benefits. Most oat food products are whole grains, using the entire groat. Food consumption of oat includes products such as oatmeal, natural cereals, cookies, breads, granola, and baby food. These products can be made from whole rolled oat, steel cut groats, oat flakes, oat flour and oat bran. Production of oat food products requires milling of the oat grain to remove the hull, which is indigestible for both humans and animals.

The primary goal of purchasing milling quality or industrial oat is to obtain grain that will result in a high quality product, and produce a high milling yield. Minimum quality standards exist and it is important that the producer be aware of the standards required; in western Canada oat must grade CW1 or CW2 to qualify. The milling requirements for high quality are appearance, flavor, moisture (maximum 15%), test weight (minimum 245 g/0.5 L), 1000 grain weight (minimum 27 g), 26% maximum hull content, minimum 90% plump kernels (>2mm diameter), double oat (maximum 0.8 %), foreign material (maximum 1%), foreign grain (maximum 3%) (Ganssmann and Vorwerck, 1995). Purchasing oat with the above quality specifications ensures economical mill operating conditions.

Determining optimum cultivar, N rate, seeding date, and seeding rate is not only necessary for achieving high oat yields, but also for improving oat milling quality. Determining the ideal management for milling quality oat could result in grade improvements, increasing per acre income by $16-24 (May and Mohr, 1998). In Saskatchewan, over the last five years, 46% of the oat harvested have graded CW3 or as feed oat (May and Mohr, 1998). At the elevator, the western Canadian grading system and prices are based on the minimum standards for three parameters: percent moisture, foreign material and grain test weight.

Research on the effects of agronomic practices on oat focus mainly on its impact on yield and yield components. Information on the effects of management on specific milling traits is limited, especially in Canada. In Australia, Zhou et al. (1998) found that although management had a significant effect on oat quality, cultivar was the main cause of most quality differences. In Canada, Humphreys et al (1994a) agreed, stating that correct cultivar choice was crucial for the production of high quality oat grain.

2.6.1 Oat Milling

The general steps in the milling process are cleaning, grading, hulling, fluff and hull separation, groat separation, steaming and kilning, groat cutting, and flaking (Gansmann and Vorwerck, 1995). The purpose of cleaning is to remove undesirable components including dust, chaff, weed seeds, and other course grains and impurities, as well as double, and thin oat. A receiving separator also removes light oat unsatisfactory for milling. Oat consist of a mixture of grains of different sizes, resulting from the biological structure of the oat panicle and its spikelets containing different sized grains.

The oat mixture is divided into streams based on size to allow further processing to be catered to each size class.

The grading process is based on either the width or thickness of the oat kernel or the length. During dehulling, the indigestible hulls are removed from the groats through impaction and abrasion. The ease with which the oat can be dehulled is based on moisture content, proportion of hull, size and 1000 grain weight, and fragility of kernels. A table separator is used to separate the groat/oat grain mixture. This process is based on physical characteristics such as specific gravity, surface texture, and response to gravitation.

Kiln drying is used to stabilize oat products for shelf life. Groat grading, cutting, and cleaning are dependent upon the type of finished product desired. The choicest larger kernels are stored separately for making large rolled oat. The remaining fraction is fed through groat cutters to produce steel cut groats, used to produce oat flakes or oatmeal. Flattening whole or cut groats between rolls under heavy pressure produces oat flakes.

Products resulting from oat milling will vary depending on the original quality of the sample and the efficiency of the mill. Approximately 170 to 180 kg of oat grain is required to produce 100 kg of products (Burnette et al., 1992).

2.6.2. Physical Milling Quality Characteristics

2.6.2.1 Test Weight

Test weight is used as the measure of grain quality at the elevator and the market value of oat, since it is effective in eliminating low bushel weight grain lots (Peek and Poehlman, 1949). However, test weight as an accurate measure of oat quality has received much attention. Zavitz (1927) found test weight to be a "poor criterion for determining the milling value of different cultivars because test weight is influenced more by kernel length than the quality of the oat grains". For example, long thin-hulled oat were found to weigh less per bushel than short plump thick-hulled oat. Peek and Poehlman (1949) agreed that test weight could not be used as an indicator of the amount of millable grains, however because of its ease of employment it will continue to be the most widely used preliminary measure of quality at the primary elevator.

Crop management can affect grain test weight. Almeida (1996) found that seeding at the earliest date resulted in superior oat test weights. As planting period was delayed, days to maturity were reduced resulting in less time for grain filling and, therefore, lower test weights. Humphreys et al. (1994a) found varying effects of delayed seeding on test weight. At one location in all three years delayed seeding reduced test weight, however the magnitude of the test weight reduction depended on cultivar. 'Manic' had the largest test weight reductions with delayed seeding while 'Newman' had the least. Test weight of the cultivar 'Newman' was not as negatively affected by delayed seeding, in these three years, as high levels of plump kernels and 1000 grain weight were maintained. In the same study N fertilization had no significant effect on grain test weight. Ciha (1983) studied oat, barley, and wheat with delayed seeding and found that averaged over years test weights were generally reduced with delayed seeding.

2.6.2.2 Groat and Hull Yields

"The oat miller is ultimately interested in how many bushels are needed to produce a barrel of millable groats" (Atkins, 1943). When making conclusions on the milling merit of a particular oat cultivar, strongest consideration should be given to hull percent, while test weight should be used as substantiating evidence. Hull percent is a definite cultivar characteristic, therefore, it is important to determine it exactly rather than using estimations through other measures. Love (1914) determined the hull percentage of a large number of oat varieties to range from 25-40%, while Zavitz (1927) determined a wider range of 21-43%.

Groat size can be affected by the number of kernels produced per spikelet and the position of the spikelet on the oat panicle. An increased proportion of tertiary grains can lower the groat content of a grain sample (Young and Shands. 1974). As groats develop in different parts of the panicle it is probable that nutrients may be limiting for younger groats located closer to the base of the panicle, producing lighter groats. With sufficient nutrients in greenhouse conditions, this effect was less pronounced. Groat weight was highest in the primary grains and decreased from the secondary to tertiary, attributed to position on the panicle (Youngs and Shands, 1974). Peltonen-Sainio (1997) found that increasing seeding rate did not significantly affect the number of tertiary grains per spikelet while Takeda and Frey (1980) found tertiary seed set to be influenced by cultivar and seeding date, with the later seeded plots producing fewer tertiary grains. As environmental factors and cultivar influence kernel set, it seems evident that increases in seeding rates, delays in seeding and fertility will play an important role in determining groat yield and size.

The influence of agronomic factors on oat hull content has been variable. Peltonen-Sainio and Peltonen (1993) found that under Northern growing conditions, hull content was negatively correlated with grain yield. Atkins (1943) also found a significant negative correlation, in high rust years, between yields and hull content. Test weight was significantly negatively correlated to hull content in both seasons. Stoa et al. (1936)

found that rust infested cultivars tended to have higher than average hull contents and earlier maturing cultivars had a relatively lower hull percent than midseason varieties.

Humphreys et al. (1994a) observed that the only significant effect of N fertilization on oat milling quality was a slight increase in groat yield. Their study also found significant cultivar x seeding date interactions for hull percent in three site years. Delayed seeding increased percent hull in all cultivars in two site years, with increases greater in 'Manic', 'Marion QC' and 'Capitol' versus 'Newman'. In another site year, hull percent was reduced or remained unchanged depending on the cultivar. It was concluded that cultivar rather than seeding date was the primary determinant of milling yield. Peltonen-Sainio (1997) found the high N fertilizer level of 120 kg/ha increased groat yield in one year but there was no significant effect of N fertilization in the second year. In the same study seeding rate did not significantly affect groat yield. Zhou et al (1998) found groat percent increased as seeding rate increased up to approximately 400 seedlings per square meter.

2.6.2.3 Plump and Thin Kernels/ Kernel size

The milling value of oat cultivars depends not only on hull content but also on the size of the kernels; plump oat (>2mm width) are used to make the choice grades of large oat flakes and are therefore most desirable (Peek and Poehlman, 1949). Thin oat (<0.8mm width) have the highest percent hull, which makes them the least desirable for milling rolled oat. A cultivar producing the largest amount of large grain sizes with the least amount of hull would be superior for milling rolled oat.

Zhou et al. (1998), working in Australia, found that N additions between 0 and 100 kg/ha, and delayed seeding did not affect the number of plump kernels. Increasing seeding rate from 70 to 400 seedlings per square meter had a significantly positive effect on the number of plump kernels, increasing the average across cultivars from 83 to 90%. Cultivar was determined to be the major determinant of kernel size across the environments studied, with the cultivars 'Echidna', 'Euro', 'Mortlock', and 'Yarran' maintaining consistently higher levels of plump kernels versus 'Cooba' and 'Bimbil'. Seeding date x cultivar interactions were important for percent plump and thin kernels, in a study in Quebec (Humphreys et al., 1994a). Grain size of the cultivar 'Newman' was not as negatively affected by late seeding while 'Capitol' was. In a cool and wet season, late seeding increased thin oat content more than other years. It is possible that the number of thin kernels is related to tertiary seed production, however literature in this area is not available. In the same experiment, in one site year out of four, application of additional N at late seeding (40 kg/ha N at seeding, plus 20 kg/ha at booting) resulted in a higher percent plump kernels and 1000 kernel weight. Again cultivar effects were the dominant determinants of high levels of plump kernels.

2.7 Summary

Oat grain yield and milling quality is determined by genotype and environmental effects on three components, the number of panicles per square meter, the number of spikelets per panicle, and the weight and number of kernels per spikelet. Crop management will impact both grain yield and quality through its effect on each of these components. In order to take advantage of any positive interactions for yield or quality, and to optimize yield, an evaluation of the impact of crop management on each of these yield components is necessary.

Very little research in the area of oat agronomy has been conducted in Western Canada. The small amount of Canadian literature available on oat management was conducted with oat cultivars that are now obsolete. A review of the literature also provides evidence that oat cultivars have differential interactions with various management practices. In order to increase oat yields in Manitoba and to encourage western Canadian producers to grow oat, it is necessary to determine the most effective and cost efficient method of managing oat. Information on seeding, and N management, for newly released Canadian cultivars, will enable producers to increase their returns and maintain their position as a major oat exporter and supplier.

3. THE EFFECT OF SEEDING DATE, CULTIVAR, AND SEEDING RATE ON THE YIELD, YIELD COMPONENTS, AND PHYSICAL MILLING QUALITY CHARACTERISTICS OF SPRING OAT

3.1 Abstract

Evaluating newly released oat cultivars for yield and quality responses at varying seeding dates and seeding rates will provide up to date information for Western Canadian oat producers. Two tall oat cultivars (AC Assiniboia, and AC Medallion) and an unregistered semidwarf line (OT 288) were observed at Morden and Winnipeg in 1998, and at Carman and Winnipeg in 1999. The experiment was conducted in a split split plot design with seeding date as the main plot, cultivar as the sub plot, and seeding rate as the sub sub plot. Seeding dates represented early, normal, and late seeding. Seeding rates were 200 and 400 seeds/m^2 in 1998 and 200, 300, and 400 seeds/m^2 in 1999, representing low, recommended, and high seeding rates respectively. Grain yield, yield components, and several physical milling quality characteristics were evaluated for all plots and their respective grain samples. Delayed seeding did not significantly reduce grain yields in three out of four site years; grain yield at the fourth site, was significantly affected by seeding date with the mid seeding date resulting in the highest grain yield. Physical milling quality traits were negatively affected by delayed seeding and several seeding date x cultivar interactions were observed; milling quality was less negatively affected by delayed seeding in AC Assiniboia than AC Medallion and OT 288. Among cultivars, OT 288 had the highest yield, kernel number, and HI, and the lowest kernel weight in all four site years. Higher yield potential of OT 288 was attributed to higher tiller and panicle number per square meter than the other cultivars in all site years. The cultivars evaluated responded similarly for grain yield to variations in seeding rates. The highest seeding rate

resulted in a higher panicle number per square meter. However, this tended to be offset by a decrease in the number of kernels per panicle and therefore kernels per square meter, accounting for the lack of increased yield with the highest seeding rate. Higher test weight, plump kernels and groat percentage and as a result superior physical milling quality resulted with early seeding and the cultivar AC Assiniboia.

3.2 Introduction

The effect of cultivar choice, seeding date and seeding rate and their interactions must be evaluated in order to optimize yield and quality of newly released oat cultivars. There is the potential for semidwarf oat cultivars to be released in Western Canada, therefore it is important to observe and compare these new cultivars to conventional taller cultivars under varying management practices.

Early seeding results in efficient use of available moisture, avoidance of disease epidemics and midsummer drought and heat. Several studies have documented negative effects of delayed seeding for both yield and milling quality characteristics (Ciha, 1983, Humphreys et al., 1994). Delayed seeding can reduce the number of days from seeding to maturity, hadtening development and lowering growth rates (Wiggans, 1956). Seeding date x cultivar interactions for grain yield have demonstrated the need to evaluate newly released cultivars under varying seeding dates (Ciha, 1983, Frey, 1959a, Wiggans, 1956). Frey (1959a) found the cultivar Andrew produced relatively higher grain yields with delayed seeding than both 'Sauk' and 'Bonham'.

Seeding rate was included in this study to observe whether higher plant population densities could offset the negative yield and quality responses observed with delayed seeding. A review of the literature revealed that the optimum seeding rates for grain yield can vary depending on the cultivar and the location (Guitard et al., 1961, Ciha, 1983). Ciha (1983) observed cultivar x seeding rate interactions for grain yield, illustrating the need to evaluate new cultivars under varying seeding rates in order to optimize yield and quality.

The objectives of this study were to: 1) observe cultivar x seeding date x seeding rate interactions for grain yield and oat milling quality, and 2) define a set of characteristics and management practices for high yielding, high quality oat crops in Manitoba. This study will also address the specific hypotheses of whether higher seeding rates can offset the yield and quality losses resulting from delayed seeding and whether semidwarf oat cultivars will result in a greater yield potential than traditional tall cultivars, due to its greater sink size and improved lodging resistance.

3.3 Materials and Methods

3.3.1 Experimental Design and Field Operations

Experiments were carried out in Morden and Winnipeg, Manitoba in 1998 and in Carman and Winnipeg, Manitoba in 1999. Details of soil type, previous crop, and indigenous soil nutrient status are provided in Table 3.1. A split-split plot design was used with seeding date as the main plot, cultivar as the subplot, and seeding rate as the sub sub plot. Four replications were used in each experiment. The length of each sub sub plot varied between 7 to 10 m., depending on the location. Each plot contained 12 rows at 15 cm spacing. A border plot, separated seeding dates to prevent the earlier seeded plots from lodging onto later seeded plots. Soil samples were collected in the spring at all locations and soil nutrient status was established (Table 3.1).

Three seeding dates were evaluated in each trial, representing early, normal, and late seeding. The time between seeding ranged from 10 to 14 days. In 1998, the seeding dates at Morden were May 13, May 25, and June 3 and the seeding dates were May 5, May 22, and June 2 in Winnipeg. In 1999, the seeding dates in Carman were April 30,

Table 3.1 Location, soil type and initial fertility of soils used in the seeding date x cultivar x seeding rate study in southern Manitoba in 1998 and 1999.

Location Soil Type Soil Texture	Winnipeg Riverdale Soil Silty Clay		Morden Altona Soil Sandy Loam	Carman Denham Loam
	1998	1999	1998	1999
Previous Crop	Fallow	Wheat	Barley	Flax
Estimated Available	kg/ha			
Nitrate NO_3-N (to 60 cm)	146	45	125	36
Phosphate P_2O_5 (to 15 cm)	112	56	38	67
Potassium K_2O (to 15 cm)	950	1073	278	1044
Sulfate S (to 60 cm)	38	38	>150	94

May 14, and June 3 and the seeding dates were, April 27, May 18, and May 27 in Winnipeg.

Three spring oat cultivars (AC Assiniboia, AC Medallion, and OT 288) with contrasting characteristics were evaluated in this study (Table 3.2). AC Assiniboia and AC Medallion are conventional, tall cultivars; OT 288 is an unregistered semidwarf line developed at the Cereal Research Centre of Agriculture and Agri-Food Canada. All three cultivars had the most current disease resistance at the onset of the experiments, including very good resistance to crown and stem rusts.

In 1998 two seeding rates were evaluated, 200 (low) and 400 (high) viable seeds/m^2. In 1999 an additional rate of 300 viable seeds/m^2 (recommended) was added to the experiments. All crops were seeded at 4 cm depth using a Fabro no till offset disc press drill (Swift Machinery Co., Swift Current, SK) with a cone seed distributor.

Nitrogen and phosphorus fertilizer was seed placed at rates of 3 kg/ha actual N and 12 kg/ha actual phosphorus (in the form of monoammonium phosphate). In 1999 ammonium nitrate was broadcast at both the Winnipeg and Carman plots at a rate of 61 kg/ha and 53 kg/ha respectively (actual N), bringing the total available N supply (including soil test N levels) to 109 and 92 kg N/ha respectively. Plots at the Winnipeg 1998 and 1999 location were sprayed with Refine Extra and MCPA at the recommended rate of 0.0198 kg/ha Refine and 1.11 L/ha MCPA. Carman 1999 plots were sprayed with Curtail at the recommended rate of 2 L/ha.

Environmental data, including monthly rainfall and mean monthly temperature, were collected from the Plant Science Department weather station in Winnipeg in 1998 and 1999, and Environment Canada in Morden 1998 and Carman 1999 (Table 3.3).

Table 3.2 Cultivar descriptions of the three oat cultivars used in the seeding date x cultivar x seeding rate experiments in southern Manitoba in 1998 and 1999 [1].

GENOTYPE	REGISTERED	HEIGHT	LODGING[2]	STEM RUST	CROWN RUST	SMUT	BYDV[3]
AC Assiniboia	yes	tall (~120cm)	VG	VG	VG	VG	G
AC Medallion	yes	tall (~120cm)	F	VG	VG	VG	P
OT 288	no	semi-dwarf (~90cm)	VG	VG	VG	VG	P

[1] According to the Manitoba Seed Guide 2000.

[2] Scale based on ratings of VG=very good, G=good,F=fair, and P=poor.

[3] Barley Yellow Dwarf Virus

Table 3.3 Mean monthly temperature and growing season precipitation for the 1998, 1999 growing seasons at three locations in southern Manitoba.

	Monthly growing season precipitation (mm)		Mean monthly Temperature (°C)	
	1998	1999	1998	1999
Winnipeg				
April	36	29	9.1	7.5
May	119	103	14.0	13.1
June	64	80	16.7	17.5
July	68	72	21.0	20.8
August	15	35	21.7	19.5
Total	302	319		
Morden				
April	53		8.8	
May	62		13.8	
June	99		15.6	
July	46		20.2	
August	36		21.1	
Total	296			
Carman				
April		15		5.5
May		142		11.8
June		74		16.0
July		83		18.8
August		39		18.1
Total		353		

Precipitation and temperature data collected from weather data recorders at each location.

3.3.2 Grain Yield and Yield Components

Grain yield and yield components were measured or calculated for each sub plot. Plant densities were established after full emergence from plant counts of two, one meter lengths of row in each sub plot. Two, one meter lengths of row were hand harvested from each sub plot at both anthesis and maturity, and were oven dried at 65 °C for at least 72 hours and weighed to establish above ground dry matter production. Tiller numbers were counted at anthesis on 10 plants per sub plot, in 1998 and were used to calculate tiller numbers per square meter. In 1999 total tillers were enumerated at anthesis, in two-one meter lengths of row per sub plot. Panicle densities were determined, at maturity, from counts of two-one meter lengths of row per sub plot in both years. Additional yield components such as seeds per panicle, panicles per plant, and kernel numbers per m^2 were determined through calculations.

Lodging notes were taken after anthesis while the crop was still green, and immediately prior to harvest, using a visual scale of 1 to 9. A rating of 1 being 100% of the plot standing straight up and 9 being 100% of the plot laying flat on the ground. Intermediate values were determined on the basis of plant angle and percentage of the plot area affected.

Plots were harvested using a small plot combine. Harvested areas for grain yield ranged from 10 to 16 m^2. Winnipeg experiments were harvested with a Hege combine, while Morden and Carman plots were harvested using a Wintersteiger combine. Eight and 10 rows were harvested with the Hege and Wintersteiger, respectively. Grain was cleaned using either a seed blower (Bill's Welding, Pullman, Washington) in 1998 or a Clipper in 1999. Grain yields were not adjusted for moisture content.

3.3.3 Physical Milling Quality Analysis

Milling quality attributes were tested from one randomly drawn sample of grain from each plot. Physical milling quality traits assessed included test weight (g/0.5L), kernel weight (mg/kernel), groat and hull content (percent), and plump and thin kernels (percent).

Test weight was determined as the weight of grain in a 0.5 L volume container after passing through a Cox funnel and leveled using a roller.

Kernel weight was determined by the number of grains in a 10 gram sample (double and dehulled grains were removed), converted to its 1000 grain weight equivalent.

Groat and hull content were calculated as a percentage, using a 70 gram whole oat sample passed through a Codema laboratory hulling machine for one minute (LH 5095, Codema Incorporated, Vancouver B.C.) (see Appendix A for settings and instructions).

Percent plump grain was determined by the weight of grain from a 20 g sample that did not pass through a 2.4 mm x 19 mm screen (double and dehulled grains were removed prior to sieving). Percent thin grain was determined by the weight of grain from a 20 g sample that passes through a 0.8 mm x 19 mm screen. The two sieve sizes were placed one on top of the other with the larger sieve size on top. The sieves were then lined up with the sieve slots facing vertically in the same direction and the sample was shaken from side to side ten times. The grain remaining on top of the 2.4 mm x 19 mm screen was weighed and considered plumps, while the grain that fell through the 0.8 mm x 19 mm screen was weighed and considered thins.

3.3.4 Statistical Analysis

Data from all site years was evaluated for homogeneity of error variances using a Bartlett's test. Due to heterogeneity of error variances, the four site years were analyzed individually using an analysis of variance (see Appendix A.1). Fisher's least significant difference test was used when the ANOVA F statistic was significant ($p<.05$). Significant interaction effects are illustrated in tables when observed consistently over site years.

3.4 Results and Discussion

3.4.1 Grain Yield and Yield Components

Delayed seeding did not significantly reduce grain yield in 1998, or in Carman in 1999 (Tables 3.4 to 3.6). A significant ($p<0.05$) seeding date effect was observed in Winnipeg 1999 (Table 3.7), where grain yield at the latest seeding date was significantly lower than the mid seeding date while early seeding did not differ significantly from either the mid or late seeding dates. These findings were contrary to several other studies which observed lower grain yields with delayed versus early season seeding (Wiggans, 1956; Nass et al., 1975; Humphreys et al., 1994a).

Critical yield determining components responded inconsistently to seeding delays, explaining the lack of yield reductions. Responses were found to be both negative and positive depending on site year (Tables 3.4 to 3.7). Delayed seeding significantly ($p<0.01$) reduced kernel weights in 1998, while in 1999, kernel weights remained constant or were increased with delayed seeding. Kernel number per square meter was only significantly affected at Carman 1999 ($p<0.05$) where late seeding resulted in fewer kernels per square meter. Seeding date effects for panicle number were significant ($p<0.05$), but not consistently positive or negative, for panicle numbers at Winnipeg 1998, and Carman and Winnipeg 1999. Delayed seeding did not affect kernels per panicle in 1998 but significantly increased kernels per panicle at Winnipeg 1999 and decreased kernels per panicle at Carman 1999. This was opposite to a study by Gooding and Lafever (1991) where delayed seeding reduced kernel weights, panicle numbers, and kernels per panicle; reductions were attributed to less favorable conditions during anthesis, seed set, and grain fill. Similarly, Frey (1959a) found that cultivars resulting in

Table 3.4 The effect of seeding date, cultivar, and seeding rate on yield and yield components at Morden 1998.

Main Effect		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No.	Tiller No.	Panicle No.	Kernels/ panicle	HI%
				per square meter				
Seeding Date								
Early		4267	38.6a	11226	515	178	63	44.1
Mid		4219	37.2b	11511	410	183	65	46.7
Late		3977	35.3c	11430	525	179	64	44
lsd (0.05)		877	1.2	2098	142	17	11	7.6
Cultivar								
OT 288		4549a	33.3c	13703a	551a	213a	66a	49.9a
AC Assiniboia		4172b	41.1a	10258b	491a	175b	60b	43.2b
AC Medallion		3766c	36.8b	10300b	411b	158c	66a	42.0b
lsd (0.05)		234	1.7	846	64	13	6	3.3
Seeding Rate								
200		4075	36.9	11215	347b	157b	70a	44.5
400		4236	37.2	11557	616a	203a	58b	45.4
lsd (0.05)		213	1.2	853	71	15	6	3.1
Source of Variation					*ANOVA (P>F)*			
	df							
Date	2	0.8221	0.0017	0.8696	0.1809	0.7950	0.8395	0.5980
Cultivar	2	0.0001	0.0001	0.0001	0.0014	0.0001	0.0348	0.0006
Rate	1	0.2657	0.4853	0.6974	0.0001	0.0001	0.0004	0.4400
DatexCutivar	4	0.0095	0.0160	0.0755	0.0551	0.4141	0.3351	0.6184
DatexRate	2	0.1996	0.8782	0.5264	0.3554	0.2783	0.5374	0.3122
CultivarxRate	2	0.0663	0.6561	0.2710	0.8560	0.3868	0.5266	0.6755
DxCxR	4	0.6849	0.3443	0.7139	0.7463	0.9390	0.9644	0.6500
CV%		10.5	6.5	15.3	29.9	15.9	16.9	14.1

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*DxCxR refers to seeding date (D), cultivar (C), and seeding rate (R).

Table 3.5 The effect of seeding date, cultivar, and seeding rate on yield and yield components at Winnipeg, 1998.

Main Effect		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No.	Tiller No.	Panicle No.	Kernels/ panicle	HI%
				per square meter				
Seeding Date								
Early		3435	36.8a	9504	419	201a	50	36.7
Mid		3229	34.5b	9495	519	149b	46	30.8
Late		3374	32.8c	10390	454	176ab	59	29.9
lsd (0.05)		462	1.1	1265	94	28	30	6.3
Cultivar								
OT 288		3819a	31.0c	12345a	528	201a	64	36.2a
AC Assiniboia		3331b	38.6a	8657b	418	163b	38	32.9a
AC Medallion		2888c	34.5b	8388b	445	164b	54	28.3b
lsd (0.05)		308	1.2	1004	94	20	24	4.2
Seeding Rate								
200		3358	34.9	9808	389b	165	61	32.4
400		3334	34.5	9785	539a	187	43	32.5
lsd (0.05)		217	0.7	563	73	22	18	3.0
Source of Variation		ANOVA (P>F)						
	df							
Date	2	0.5644	0.0004	0.2185	0.0991	0.0125	0.6781	0.0779
Cultivar	2	0.0010	0.0001	0.0001	0.0596	0.0020	0.0931	0.0032
Rate	1	0.8226	0.3513	0.9332	0.0003	0.0634	0.0765	0.9253
DatexCutivar	4	0.1903	0.0737	0.4579	0.4356	0.4343	0.2424	0.3756
DatexRate	2	0.6536	0.4332	0.3218	0.4077	0.0733	0.3751	0.4122
CultivarxRate	2	0.3852	0.1445	0.2544	0.4719	0.4432	0.4726	0.5883
DxCxR	4	0.6537	0.3750	0.2862	0.4304	0.2667	0.2748	0.3904
CV%		13.4	4.2	11.9	32.6	25.3	71.6	19.1

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*DxCxR refers to seeding date (D), cultivar (C), and seeding rate (R).

Table 3.6 The effect of seeding date, cultivar, and seeding rate on yield and yield components at Carman 1999.

Main Effect		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No.	Tiller No.	Panicle No.	Kernels/ panicle	HI%
				per square meter				
Seeding Date								
Early		4518	37.1b	12254a	411a	269a	46b	38.7
Mid		4568	36.2b	12720a	359b	244b	53a	41.2
Late		4386	39.0a	11333b	312c	275a	42c	40.8
lsd (0.05)		290	1.3	822	46	16.4	3	2.5
Cultivar								
OT 288		4950a	35.4c	14031a	394a	291a	50a	44.0a
AC Assiniboia		4194b	40.3a	10415c	341b	248b	43b	38.0b
AC Medallion		4318b	36.5b	11852b	347b	250b	49a	38.4b
lsd (0.05)		158	0.6	479	22	18	4	2.4
Seeding Rate								
200		4435	37.3	12007	343b	248b	50a	39.7
300		4570	37.4	12299	364a	257b	49a	39.7
400		4464	37.5	11999	375a	284a	43b	39.9
lsd (0.05)		164	0.7	470	18	13	3	2.3
Source of Variation		ANOVA (P>F)						
	df							
Date	2	0.2959	0.0071	0.0152	0.0056	0.0081	0.0005	0.1262
Cultivar	2	0.0001	0.0001	0.0001	0.0001	0.0010	0.0022	0.0001
Rate	2	0.1780	0.9104	0.3135	0.0030	0.0001	0.0001	0.4113
DatexCutivar	4	0.2035	0.0025	0.9925	0.5914	0.4428	0.7259	0.5353
DatexRate	4	0.6896	0.9562	0.6332	0.3749	0.9562	0.6230	0.8586
CultivarxRate	4	0.4954	0.0428	0.7627	0.7558	0.6593	0.6006	0.6045
DxCxR	8	0.5359	0.7417	0.4446	0.5411	0.4033	0.5120	0.4709
CV%		7.6	3.7	8.1	10.8	10.2	13.6	12.2

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*DxCxR refers to seeding date (D), cultivar (C), and seeding rate (R).

Table 3.7 The effect of seeding date, cultivar, and seeding rate on yield and yield components at Winnipeg 1999.

Main Effect		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No.	Tiller No.	Panicle No.	Kernels/ panicle	HI%
				per square meter				
Seeding Date								
Early		3958ab	33.8	11877	405a	245a	49b	36.5b
Mid		4209a	33.5	12754	317b	259a	51b	39.8b
Late		3837b	33.3	11745	251c	187b	64a	45.4a
lsd (0.05)		275	0.6	893	34	26	7	3.9
Cultivar								
OT 288		4439a	29.6c	14997a	364a	255a	62a	44.4a
AC Assiniboia		3873b	37.2a	10412b	320b	219b	50b	40.0b
AC Medallion		3692b	33.8b	10967b	289c	217b	52b	37.4b
lsd (0.05)		190	0.5	644	28	23	6	2.7
Seeding Rate								
200		4028	33.1b	12373	305b	213b	60a	41.3
300		3994	33.6ab	12043	327a	232a	53a	40.1
400		3982	33.8a	11961	340a	247a	51b	40.4
lsd (0.05)		123	0.5	434	20	17	5	2.2
Source of Variation	df	ANOVA (P>F)						
Date	2	0.0410	0.1707	0.0635	0.0001	0.0011	0.0030	0.0039
Cultivar	2	0.0001	0.0001	0.0001	0.0001	0.0035	0.0032	0.0001
Rate	2	0.7410	0.0468	0.1414	0.0029	0.0005	0.0007	0.5280
DatexCutivar	4	0.5794	0.0019	0.2101	0.0222	0.8347	0.2250	0.6343
DatexRate	4	0.0136	0.8012	0.0858	0.6370	0.1788	0.0715	0.7348
CultivarxRate	4	0.3751	0.2971	0.3150	0.1410	0.4166	0.1109	0.0448
DxCxR	8	0.3127	0.3894	0.3477	0.4819	0.9930	0.9797	0.4331
CV%		6.5	3.4	7.6	13.1	15.2	17.9	11.5

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*DxCxR refers to seeding date (D), cultivar (C), and seeding rate (R).

lower yields with later seeding did so because of lower kernel weights, fewer panicles per plant, and fewer kernels per panicle.

Low air temperature during critical development periods may have been a factor lending to a lack of yield reduction with delayed seeding. Gooding and Lafever (1991) and Fulton (1968) suggested that high temperatures during grain fill caused yield reduction in oat, while Entz and Fowler (1991) observed similar trends in wheat. Air temperatures in the study by Fulton (1968) were 24 °C while the mean monthly temperature in July for the present study ranged from 18.8 to 21.0 °C (Table 3.3).

Studies by Wiggans (1956) and Nass et al. (1975) found that disease occurrence and severity increased with later seeding. The cultivars evaluated in these trials contain resistance genes for prevalent races of both crown and stem rust, reducing potential yield loss due to disease.

A significant seeding date x cultivar effect for grain yield was observed only at Morden 1998 (Table 3.4), where AC Medallion was more negatively affected by delayed seeding than other cultivars due to significantly lower tiller and panicle densities. The low frequency of interaction effects in the present study is inconsistent with studies by Frey (1959a), Ciha (1983) and Humphreys et al. (1994a) who reported cultivars with differential sensitivity to seeding delays.

Delayed seeding is often used as a tool for wild oat control (Principles and practices of Commercial Farming, 1968). Since delayed seeding rarely reduced grain yield in this study, this type of late seeding weed control can be used, without significant yield reductions. The lack of yield loss with delayed seeding also demonstrates the suitability of the cultivars evaluated to Manitoba growing conditions.

Cultivar effects were significant for all yield components at Morden 1998, Carman 1999, and Winnipeg 1999 (Tables 3.4, 3.6, 3.7). In Winnipeg 1998, cultivar effects were significant for yield, kernel weight, kernel number, panicle number and HI (Table 3.5). OT 288 was the highest yielding cultivar, had the highest kernel and panicle numbers per square meter and harvest indexes, and the lowest kernel weights in all four site years (Tables 3.4 to 3.7). Cultivar effects on tiller and panicle density and kernels per panicle can be found in Figure 3.1. Higher harvest indexes suggest that the semidwarf was more efficient at partitioning dry matter into grain yield, consistent with other semidwarf cereals (Anderson and Maclean, 1989). Kernel numbers per square meter are a function of panicles per square meter and kernels per panicle. In the present study, greater panicle numbers largely determined higher kernel numbers ($r=0.48^{***}$) (Table 3.8). OT 288 produced more tillers and panicles per square meter than the two tall cultivars. These results were similar to an Australian study by Anderson and Maclean (1989), where tiller and panicle numbers were higher in the semidwarf 'Echidna', but were contrary to a study by Meyers et al. (1985) where panicle densities were similar among tall and semidwarf cultivars.

Averaged over treatments, AC Assiniboia outyielded AC Medallion in 1998 however yields were similar in 1999 (Tables 3.4 to 3.7). AC Assiniboia had the highest kernel weights in all four site years. The taller cultivars, AC Assiniboia and AC Medallion resulted in similar harvest indexes except in Winnipeg 1998 when HI was lower in AC Medallion (Tables 3.4 to 3.7).

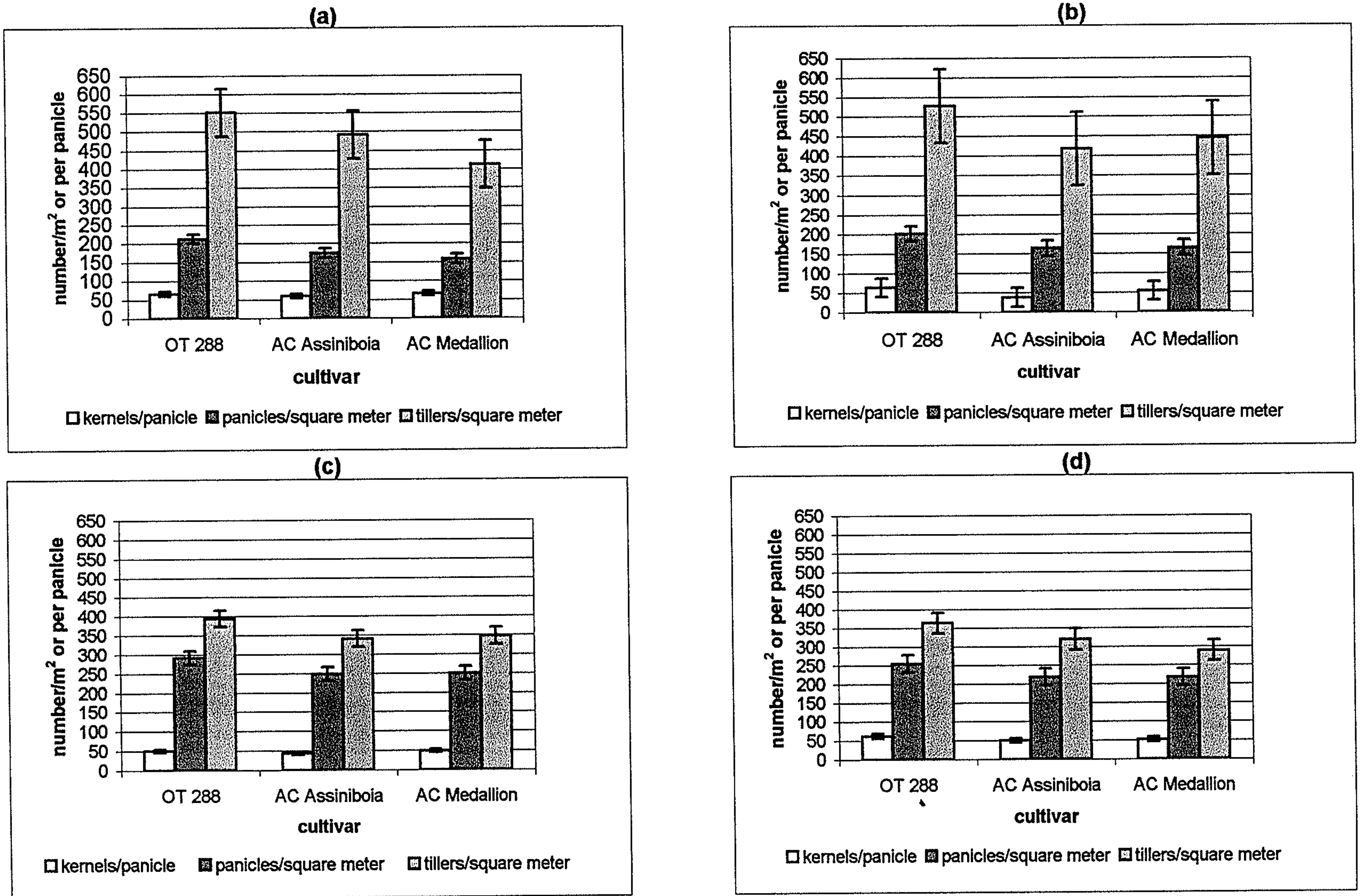

Figure 3.1 Effect of cultivar on yield components of oats at a)Morden in 1998, b)Winnipeg in 1998, c)Carman in 1999, and d)Winnipeg in 1999. (Standard error bars represent the least significant difference for cultivar).

Table 3.8 Pooled Pearson Correlation Coefficients (values per plot) among grain yield and yield components of three oat cultivars grown over four environments in Carman, Morden, and Winnipeg in 1998 and 1999.

Variables Correlated	1998 Sites		1999 Sites		Across Sites
	Morden	Winnipeg	Carman	Winnipeg	
Grain Yield vs. Kernel No.	0.82***	0.89***	0.89***	0.88***	0.84***
Grain Yield vs. Kernel Wt.	-0.07	-0.14	-0.29**	-0.38***	-0.01
Grain Yield vs. Panicle No.	0.45***	0.23	0.48***	0.44***	0.53***
Grain Yield vs. Kernels/Panicle	0.32**	0.58***	0.33**	0.29**	0.17**
Panicle No. vs. Kernel No.	0.53***	0.25*	0.40***	0.42***	0.48***
Panicle No. vs. Kernel Wt.	-0.30*	-0.12	-0.08	-0.24*	-0.08
Panicle No. vs. Kernels/Panicle	-0.50***	-0.53***	-0.58***	-0.62***	-0.63***
Kernels/Panicle vs. Kernel No.	0.44**	0.65***	0.49***	0.40***	0.34***
Kernels/Panicle vs. Kernel Wt.	-0.33**	-0.39**	-0.51***	-0.39***	-0.35***
Kernel No. vs. Kernel Wt.	-0.62***	-0.57***	-0.70***	-0.77***	-0.54***

Seeding rate affected panicle density and kernels per panicle at all site years (Tables 3.4 to 3.7, and Figure 3.2). In 1998, more panicles were observed in the 400 seeds/m^2 treatment than 200 seeds/m^2. At Carman 1999, 200 and 300 seeds/m^2 treatments had similar panicle numbers vs. 400 seeds/m^2, which produced the most panicles. At Winnipeg 1999, 300 and 400 seeds/m^2 had higher panicle numbers than 200 seeds/m^2. In all four site years, 400 seeds/m^2 resulted in fewer kernels per panicle and a greater panicle density, compared with either 200 seeds/m^2 or 200 and 300 seeds/m^2. In the 400 seeds/m^2 treatment, kernel numbers similar to the 200 or 300 seeds/m^2 treatments were distributed over a greater number of panicles per square meter resulting in relatively constant numbers of kernels per square meter. Due to this inverse relationship between panicles per meter square and kernels per panicle, i.e. as panicle numbers increased, kernels per panicle decreased, the number of kernels per square meter was unaffected by seeding rate increases, indicating a high seeding rate is an ineffective tool to increase grain yield. Jones and Hayes (1967) and Guitard et al. (1961) observed a similar relationship between panicle number and kernels per panicle. Although increasing seeding rate did not increase grain yield, a vigorous plant stand, competitive with weeds, may warrant the additional cost of a heavier seeding rate when wild oat infestations exist. This was confirmed by a Saskatchewan study which found that under high wild oat (*Avena fatua L.*) infestations, increasing seeding rate resulted in increased grain yields (Bill May, personal communication, Indian Head Saskatchewan, Agriculture and Agri-Food Canada).

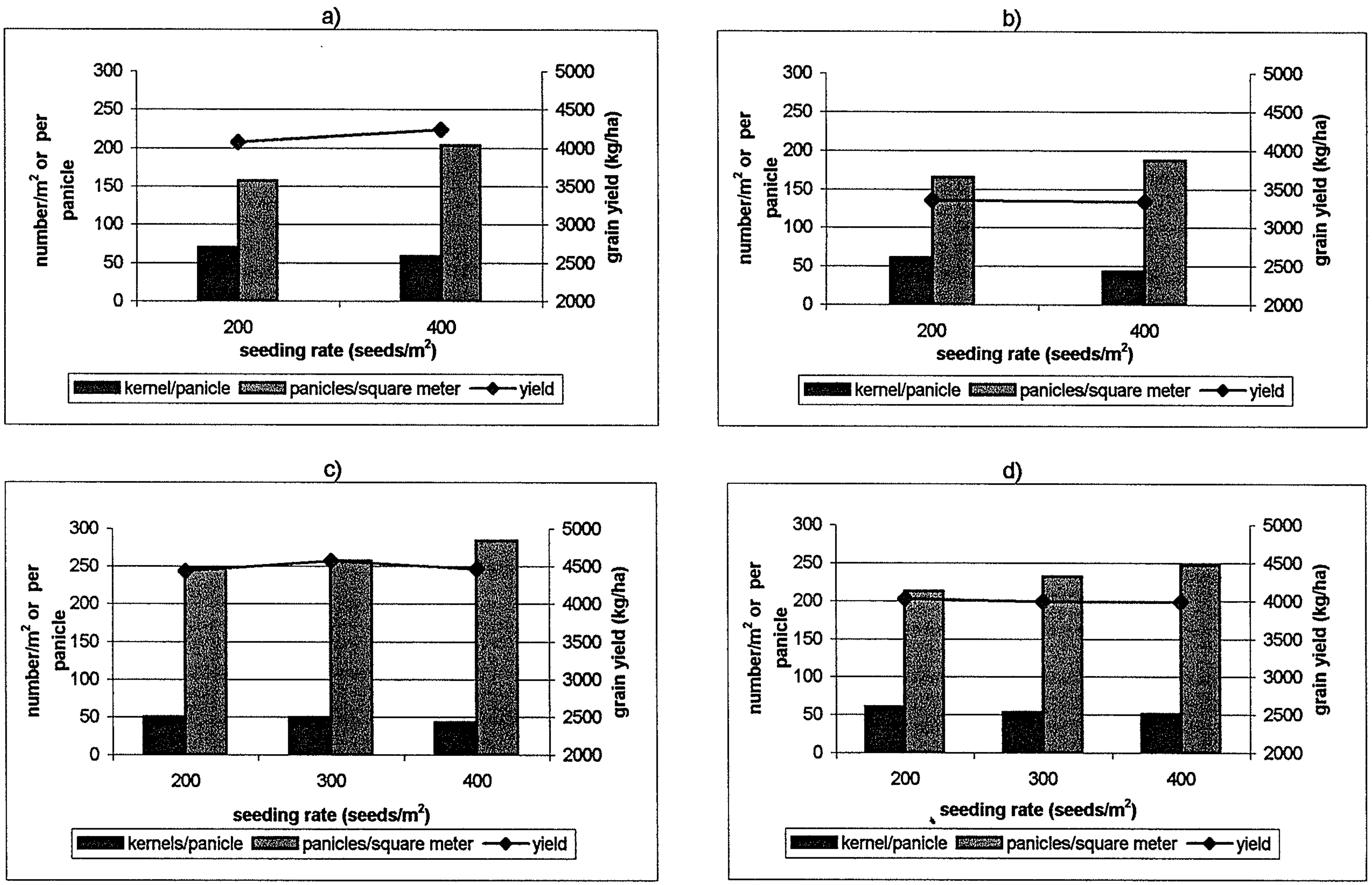

Figure 3.2 Effect of increasing seeding rate on the number of kernels per panicle, panicles per m^2, and yield at a) Morden 1998, b) Winnipeg 1998, c) Carman 1999, d) Winnipeg 1999.

A seeding date x cultivar effect was found for kernel weight at Morden 1998 and Carman and Winnipeg 1999 (Tables 3.9 to 3.11). Kernel weights of AC Assiniboia were either maintained or increased (Carman 1999) with delayed seeding. AC Medallion maintained kernel weight except with the latest date at Morden in 1998. Kernel weights of OT 288 were reduced with delayed seeding at both Morden 1998 and Winnipeg 1999. Overall the AC Assiniboia displayed superior kernel weights with delayed seeding, while OT 288 had generally lower kernel weights. Other significant interaction effects can be found in Tables 3.6 and 3.7.

Kernel number per square meter was the yield component most highly correlated with grain yield across sites (r=0.84***) followed by panicle numbers per square meter (r=0.53***) (Table 3.8 and Figure 3.3). Panicle number (r=0.48***), was also positively correlated to kernel number and had an inverse relationship with the number of kernels per panicle (r=-0.63***). This illustrates the importance of panicle numbers versus kernels per panicle in determining yield as the correlation between kernels per panicle and grain yield was r=0.17**. This was similar to a study in wheat conducted by Shanahan et al. (1984) where variation in kernel number across sites was also positively correlated to spike number. Kernel mass was not significantly correlated to grain yield in 1998, contrary to findings by McKee et al. (1979) but was negatively correlated to yield at both sites in 1999. Kernel number was inversely related to kernel weight in all site years and across sites (r=-0.54***), similar to findings for wheat by Shanahan et al. (1984) (Figure 3.3).

Table 3.9 Kernel weights of cultivars seeded at early, mid, and late dates Morden 1998.

Cultivar	Seeding Date		
	Early May	Mid May	Early June
	kernel weight (mg/kernel)		
AC Assiniboia	41.3	40.8	41.1
AC Medallion	40.1	37.6	32.6
OT 288	34.4	33.3	31.9
lsd = 1.2			

Table 3.10 Kernel weights of cultivars seeded at early, mid, and late dates Carman 1999.

Cultivar	Seeding Date		
	Late April	Early May	Mid May
	kernel weight (mg/kernel)		
AC Assiniboia	39.8	39.1	42.2
AC Medallion	36.5	36.2	36.8
OT 288	35.1	33.4	37.7
lsd = 1.3			

Table 3.11 Kernel weights of cultivars seeded at early, mid, and late dates Winnipeg 1999.

Cultivar	Seeding Date		
	Late April	Early May	Mid May
	kernel weight (mg/kernel)		
AC Assiniboia	37.4	37.5	36.6
AC Medallion	33.5	33.5	34.4
OT 288	30.5	29.6	28.8
lsd = 0.6			

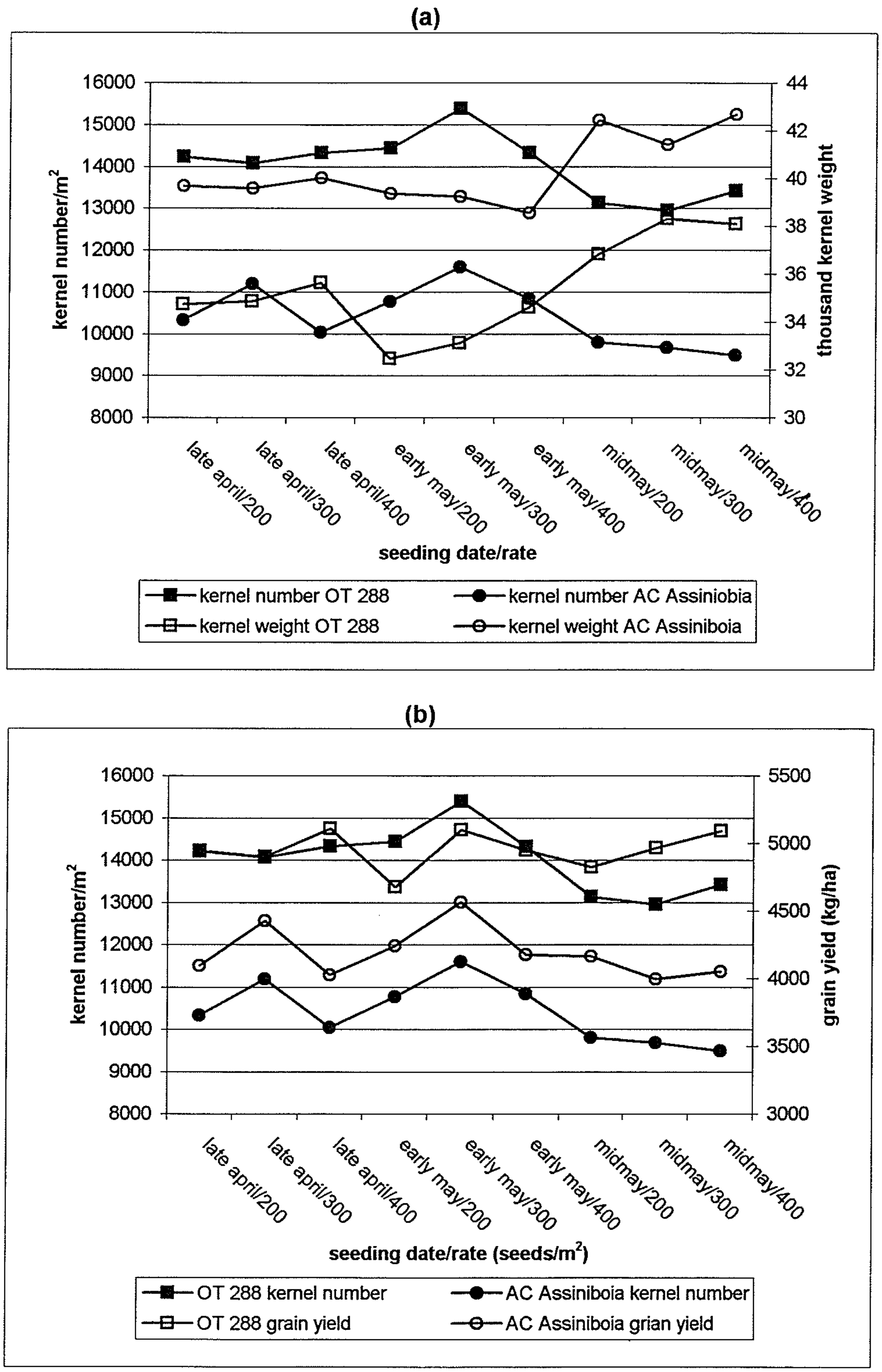

Figure 3.3 a) Kernel number and kernel weight response of cultivars OT 288 and AC Assiniboia to seeding date and seeding rate, Carman 1999. b) Kernel number and grain yield response of cultivars OT 288 and AC Assiniboia,to seeding date and seeding rate, Carman 1999.

The number of kernel sites available for grain fill, or sink size, is established upon kernel differentiation. In the present study, kernel number or sink size was largely determined by genotype, similar to a study by Duguid (1990) in wheat. On the other hand, seeding rate and early seeding did not increase sink size. This may explain why early seeding and increased seeding rates were ineffective in increasing yield. Averaged across environments, kernel weight was not correlated to grain yield, but was correlated to grain yield at Carman and Winnipeg in 1999. Although increased sink size led to increased yield, both kernel number and kernels per panicle were negatively related to kernel weight. This suggests that the inverse relationship between kernel weight and kernel number may be a limiting factor to increasing grain yields with the cultivars studied.

These findings for oat are similar to studies in wheat conducted by Fischer et al. (1977), Shanahan et al. (1984), and Duguid (1990). Fischer et al. (1977) and Shanahan et al. (1984) also found a negative relationship between kernel weight and kernel number and kernel number per spike, indicating a competition between developing kernels for limited assimilate availability. In spite of yield being sink limited, reflected by the stronger association between grain yield and kernel number, versus yield and kernel weight (Shanahan et al. 1984), there was evidence that a source limitation to oat yield does exist. However, due to the stronger correlation between kernel number and grain yield and the absence of a correlation between kernel weight and grain yield, sink strength during grain filling is clearly more important than source strength.

Although the semidwarf, OT 288, illustrates the potential to improve oat yields through increased sink size or kernel number, this was achieved at the detriment of kernel weight. OT 288 produced a greater panicles density and therefore a larger sink size, resulting in dry matter distribution over a greater number of kernel sites. This observation again illustrates the competitive relationship between developing kernels and a limited assimilate supply during grain fill, limiting grain yield. Early seeding and higher seeding rates with OT 288 could not overcome this relationship, suggesting that this inverse kernel number vs. kernel relationship is indeed a limitation to grain yield and kernel weight in oat.

Other studies have suggested that semidwarf oat cultivars may require different management than conventional tall oat cultivars (Anderson and Maclean, 1989). However, this was not suggested in this study as OT 288 produced exceptional yields across a range of seeding dates, seeding rates, and locations in comparison to the tall cultivars. Limitations of OT 288 were observed in grain quality, which was determined by genotype and therefore could not be overcome with changes in seeding date or seeding rate management. Observation of a semidwarf cultivar with genetically superior milling quality to OT 288 would assist in confirming whether different management is required in order to achieve high quality with semi dwarf oat.

3.4.2 Physical Milling Quality Characteristics

Delayed seeding negatively affected milling quality (Tables 3.12 to 3.15). For example, test weight was significantly ($p<0.01$) reduced with delayed seeding at Morden 1998, Carman 1999, and Winnipeg 1999. Delayed seeding also significantly ($p<0.05$) lowered groat percentage at Morden 1998, Winnipeg 1998, and Winnipeg 1999, by 1 to 2%. Delayed seeding reduced percent plump kernels at all site years. At Morden 1998, Winnipeg 1998, and Winnipeg 1999 delayed seeding significantly increased percent thin kernels.

Cultivar effects were significant ($p<0.01$) for test weight in all four site years; OT 288 had higher test weights than AC Assiniboia and AC Medallion, while AC Assiniboia and AC Medallion resulted in similar test weights (Tables 3.12 to 3.15). High test weight can be achieved in at least two ways. The first results from a high proportion of plump kernels, with a high groat content as demonstrated in AC Assiniboia and AC Medallion. The second mechanism demonstrated in OT 288, results from a large number of smaller kernels with a greater hull content. As thin hulled oat are found to weigh less than thick hulled oat this results in a higher test weight (Atkins, 1943). Test weight is used to indicate superior milling quality. In this study, however, high test weight was not positively correlated (R^2=0.05 to 0.30) to other important quality parameters such as plump kernels and groat percentage.

Cultivar effects were significant for groat percentage and percent plump and thin kernels in all site years; OT 288 had significantly lower groat percentages and plump kernels in all site years, while AC Assiniboia resulted in higher groat percentages and plump kernels. These results support the theory (Scott Duguid, personal communication,

Table 3.12 The effect of seeding date, cultivar, and seeding rate on lodging and milling quality at Morden 1998.

Main Effect		Lodging (scale 1-9)	Test Wt. (g/0.5l)	Groat	Plumps	Thins
				%		
Seeding Date						
Early		4.8a	250a	72.0a	83.6a	1.3c
Mid		2.7b	241b	71.0a	76.4b	2.0b
Late		3.7ab	236b	68.5b	69.3c	3.4a
lsd (0.05)		1.5	6	1.5	5.1	0.5
Cultivar						
OT 288		1.8c	249a	69.1c	69.8c	2.4b
AC Assiniboia		5.5a	238c	71.7a	85.1a	1.1c
AC Medallion		3.8b	241b	70.6b	74.4b	3.2a
lsd (0.05)		1	3	0.7	2.4	0.5
Seeding Rate						
200		3.5b	241b	70.1b	76.4	2.4a
400		4.0a	244a	70.9a	76.7	2.1b
lsd (0.05)		0.3	2	0.5	1.9	0.3
Source of Variation		ANOVA (P>F)				
	df					
Date	2	0.0392	0.0045	0.0043	0.0012	0.0001
Cultivar	2	0.0001	0.0001	0.0001	0.0001	0.0001
Rate	1	0.0039	0.0004	0.0029	0.3009	0.0434
DatexCutivar	4	0.4225	0.0038	0.0024	0.0004	0.0001
DatexRate	2	0.6100	0.1179	0.0960	0.0535	0.4504
CultivarxRate	2	0.3707	0.3434	0.8826	0.3984	0.6856
DxCxR	4	0.6191	0.0510	0.0870	0.0040	0.1626
CV%		19.3	1.3	1.5	5.1	30.6

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*DxCxR refers to seeding date (D), cultivar (C), and seeding rate (R).

Table 3.13 The effect of seeding date, cultivar, and seeding rate on lodging and milling quality at Winnipeg, 1998.

Main Effect		Lodging (scale 1-9)	Test Wt. (g/0.5l)	Groat	Plumps	Thins
				%		
Seeding Date						
Early		2.6b	245	70.6a	80.0a	1.9c
Mid		6.4a	247	70.9a	67.6b	3.3b
Late		7.1a	238	68.0b	54.2c	4.7a
lsd (0.05)		2.3	9	1.9	7.4	1.2
Cultivar						
OT 288		4.9	248a	68.3b	61.8b	3.7a
AC Assiniboia		5.3	243b	70.6a	75.8a	2.1b
AC Medallion		5.9	241b	70.5a	64.3b	4.2a
lsd (0.05)		1	4	0.9	4.4	0.9
Seeding Rate						
200		5.4	243	69.7	66.9	3.4
400		5.3	245	69.9	67.7	3.2
lsd (0.05)		0.2	2	0.5	2.5	0.5
Source of Variation		ANOVA (P>F)				
	df					
Date	2	0.0058	0.0828	0.0168	0.0004	0.0044
Cultivar	2	0.1744	0.0049	0.0001	0.0001	0.0001
Rate	1	0.4127	0.0763	0.3514	0.5530	0.6021
DatexCutivar	4	0.0540	0.1170	0.6527	0.1157	0.1350
DatexRate	2	0.7955	0.4775	0.4377	0.0340	0.5334
CultivarxRate	2	0.2174	0.7456	0.6137	0.2439	0.0558
DxCxR	4	0.3529	0.3136	0.4791	0.6707	0.1350
CV%		7.9	1.6	1.6	7.6	31.5

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*DxCxR refers to seeding date (D), cultivar (C), and seeding rate (R).

Table 3.14 The effect of seeding date, cultivar, and seeding rate on lodging and milling quality at Carman 1999.

Main Effect		Lodging (scale 1-9)	Test Wt. (g/0.5l)	Groat	Plumps	Thins
				%		
Seeding Date						
Early		2.7	250a	70.5	78.9	0.8
Mid		2.4	244b	69.8	72.3	1.2
Late		1.8	236c	69.3	75	1.2
lsd (0.05)		1.2	3	1.1	8.2	0.4
Cultivar						
OT 288		1.0b	246a	68.3c	63.0c	1.2a
AC Assiniboia		1.3a	242b	71.5a	85.1a	0.7b
AC Medallion		4.7a	242b	69.9b	78.3b	1.3a
lsd (0.05)		1.2	2	0.5	3.6	0.2
Seeding Rate						
200		1.7c	243b	69.9	76.5	1.1
300		2.4b	243b	70.1	76	1.0
400		2.8a	245a	69.8	73.7	1.2
lsd (0.05)		0.4	1	0.4	2.9	0.2
Source of Variation		ANOVA (P>F)				
	df					
Date	2	0.1120	0.0001	0.0848	0.2201	0.0610
Cultivar	2	0.0001	0.0007	0.0001	0.0001	0.0001
Rate	2	0.0002	0.0026	0.1605	0.1351	0.1362
DatexCutivar	4	0.2798	0.5197	0.0032	0.0058	0.0033
DatexRate	4	0.5018	0.2585	0.5213	0.5921	0.7837
CultivarxRate	4	0.0001	0.0847	0.8182	0.5742	0.5434
DxCxR	8	0.5061	0.4908	0.6201	0.5456	0.8385
CV%		37.7	1.1	1.1	8.1	34.4

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*DxCxR refers to seeding date (D), cultivar (C), and seeding rate (R).

Table 3.15 The effect of seeding date, cultivar, and seeding rate on lodging and milling quality at Winnipeg 1999.

Main Effect	Lodging (scale 1-9)	Test Wt. (g/0.5l)	Groat	Plumps	Thins
			%		
Seeding Date					
Early	1.0b	257b	70.8a	69.7a	1.2c
Mid	3.9a	261a	71.0a	69.3a	1.7b
Late	1.2a	247c	68.8b	61.2b	2.8a
lsd (0.05)	1.9	3	0.5	2	0.4
Cultivar					
OT 288	1.0b	258a	68.6c	54.9c	2.1a
AC Assiniboia	2.1a	253b	71.4a	75.7a	1.4b
AC Medallion	2.9a	253b	70.6b	69.6b	2.2a
lsd (0.05)	0.9	2	0.4	2.3	0.3
Seeding Rate					
200	1.9	254b	69.8b	64.4b	2.3a
300	2.0	254b	70.1b	67.1a	1.7b
400	2.1	256a	70.6a	68.6a	1.6b
lsd (0.05)	0.3	1	0.3	1.6	0.3

Source of Variation	df	ANOVA (P>F)				
Date	2	0.0176	0.0001	0.0001	0.0001	0.0002
Cultivar	2	0.0012	0.0001	0.0001	0.0001	0.0001
Rate	2	0.4227	0.0118	0.0001	0.0001	0.0001
DatexCutivar	4	0.0007	0.0632	0.0232	0.0008	0.0021
DatexRate	4	0.4850	0.2244	0.2353	0.0346	0.6721
CultivarxRate	4	0.7358	0.5940	0.0248	0.0070	0.5970
*DxCxR	8	0.8509	0.4082	0.0422	0.0322	0.2924
CV%		27	1.1	1.0	5.1	32.3

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*DxCxR refers to seeding date (D), cultivar (C), and seeding rate (R).

Morden, Agriculture and Agri-Food Canada) that the high test weight of OT 288 is the result of the second mechanism to achieving high test weight, which is a greater number of smaller kernels with a greater hull content packing into the 0.5 L container.

The highest seeding rate (400 seeds/m^2) significantly increased test weight ($p<0.05$) relative to the lower seeding rates at Morden 1998, Winnipeg 1999, and Carman 1999; increases ranged from 1 to 2 grams per 0.5 L volume (Tables 3.12, 3.14, 3.15). At Morden 1998 and Winnipeg 1999, this may have resulted from fewer kernels per panicle at the higher seeding rate (Tables 3.4 and 3.7), resulting in dry matter distribution over a smaller number of kernels and therefore causing a greater proportion of plump, heavier, kernels. Seeding rate effects on groat percentage were significant ($p<.003$) in Morden 1998 and Winnipeg 1999; the high seeding rate increased groat percentage. This may again be due to a greater proportion of plump kernels with a lower hull content due to fewer kernels per panicle and therefore a greater proportion of dry matter distributed into the groats, in the high seeding rate treatment (Tables 3.12, 3.15). Seeding rate effects were significant for kernels size distribution in Morden 1998 and Winnipeg 1999. For example, Winnipeg 1999, increasing seeding rate from 200 seeds/m^2 to 300 or 400 seeds/m^2 resulted in an increase in percent plump kernels and a decrease in percent thin kernels. However, seeding rate did not consistently affect milling quality traits across locations and years. For example, in Winnipeg in 1998 seeding rate did not consistently improve milling quality traits and therefore may not provide an economic benefit.

Significant seeding date x cultivar effects were observed for milling quality in a number of instances. A significant ($p<0.01$) seeding date x cultivar effect for test weight was observed at Morden 1998 (Table 3.12), indicating that in the remaining three site years, cultivars responded similarly for test weight, i.e. all cultivars resulted in test weight reductions with delayed seeding. Significant ($p<0.01$) seeding date x cultivar interactions were found for groat percentage at Morden 1998, Carman 1999, and Winnipeg 1999 (Tables 3.12, 3.14, 3.15). In all cases, delayed seeding had a more negative effect on the groat percentages of AC Medallion and OT 288 than AC Assiniboia (Tables 3.16, 3.17, 3.18). Seeding date x cultivar effects were significant for percent plump and thin kernels at Morden 1998, Carman 1999 and Winnipeg 1999; delayed seeding resulted in larger reductions in percent plump kernels and larger increases in percent thin kernels in AC Medallion and OT 288 vs. AC Assiniboia (Tables 3.19 to 3.24).

When seeding delays are unavoidable or desirable in the case of wild oat control, producers can take advantage of the positive cultivar x seeding date interactions for milling quality, as observed with AC Assiniboia. AC Assiniboia resulted in extremely consistent quality performance across diverse environments; at late seeding it consistently resulted in a high percentage of plump kernels and groats. These results are similar to a study by Humphreys et al. (1994a) where the cultivar 'Newman' resulted in superior milling quality across seeding dates and N rates. The cultivars 'Newman' and 'AC Assiniboia' were better able to maintain kernel mass with late seeding, resulting in superior milling quality. Such observations demonstrate the importance of cultivar in maintaining oat quality across environments. Other significant interaction effects can be found in Tables 3.12, 3.13, and 3.15.

The use of grain test weight as a means of determining oat grain price and grade has been questioned due to the inconsistency of its correlation to groat percentage

Table 3.16 Groat percentage of cultivars seeded at early, mid, and late dates Morden 1998.

Cultivar	Seeding Date		
	Early May	Mid May	Early June
	groat (%)		
AC Assiniboia	72.8	72.2	70.2
AC Medallion	73.0	71.6	67.3
OT 288	70.1	69.1	68.0
lsd = 1.5			

Table 3.17 Groat percentage of cultivars seeded at early, mid, and late dates Carman 1999.

Cultivar	Seeding Date		
	Late April	Early May	Mid May
	groat (%)		
AC Assiniboia	72.3	70.9	71.4
AC Medallion	70.4	70.6	68.4
OT 288	68.9	68.0	68.1
lsd = 1.1			

Table 3.18 Groat percentage of cultivars seeded at early, mid, and late dates Winnipeg 1999.

Cultivar	Seeding Date		
	Late April	Early May	Mid May
	groat (%)		
AC Assiniboia	71.5	72.2	70.3
AC Medallion	71.3	71.4	69.3
OT 288	69.6	69.4	66.8
lsd = 0.5			

Table 3.19 Percentage of kernels >2.4x19 mm of cultivars seeded at early, mid, and late dates Morden 1998.

	Seeding Date		
Cultivar	Early May	Mid May	Early June
	plump kernels (%)		
AC Assiniboia	89.0	85.4	80.9
AC Medallion	85.0	76.3	61.9
OT 288	76.9	67.5	64.4
lsd = 5.1			

Table 3.20 Percentage of kernels >2.4x19 mm of cultivars seeded at early, mid, and late dates Carman 1999.

	Seeding Date		
Cultivar	Late April	Early May	Mid May
	plump kernels (%)		
AC Assiniboia	87.3	82.1	85.8
AC Medallion	80.5	80.4	73.5
OT 288	68.9	54.5	65.5
lsd = 8.2			

Table 3.21 Percentage of kernels >2.4x19 mm of cultivars seeded at early, mid, and late dates Winnipeg 1999.

	Seeding Date		
Cultivar	Late April	Early May	Mid May
	plump kernels (%)		
AC Assiniboia	76.7	79.1	71.4
AC Medallion	71.6	69.9	67.4
OT 288	60.8	59.0	44.8
lsd = 2.0			

Table 3.22 Percentage of kernels <0.8x19mm of cultivars seeded at early, mid, and late dates Morden 1998.

Cultivar	Seeding Date		
	Early May	Mid May	Early June
	thin kernels (%)		
AC Assiniboia	0.9	1.0	1.5
AC Medallion	1.3	2.4	5.8
OT 288	1.8	2.6	2.9
lsd = 0.5			

Table 3.23 Percentage of kernels <0.8x19mm of cultivars seeded at early, mid, and late dates Carman 1999.

Cultivar	Seeding Date		
	Late April	Early May	Mid May
	thin kernels (%)		
AC Assiniboia	0.5	0.8	0.8
AC Medallion	1.1	1.2	1.8
OT 288	0.8	1.6	1.2
lsd= 0.4			

Table 3.24 Percentage of kernels <0.8x19mm of cultivars seeded at early, mid, and late dates Winnipeg 1999.

Cultivar	Seeding Date		
	Late April	Early May	Mid May
	thin kernels (%)		
AC Assiniboia	1.1	1.2	1.8
AC Medallion	1.4	2.1	3.1
OT 288	1.1	1.6	3.5
lsd = 0.4			

(Zavitz, 1927; Peek and Poehlman, 1949). Test weight variability accounted for a low degree of variation in milling quality traits in this study while kernel weight was a better indicator of overall milling quality (Figure 3.4). Kernel weight was significantly correlated to percent plump kernels (r=0.77***), percent thin kernels (r=-0.52***), and groat percentage (r=0.56***) (Table 3.8). Determination of both test weight and kernel weight can be easily measured at the elevator. This suggests that the producer would be more accurately paid for milling quality, through an evaluation of kernel weight rather than test weight.

Other significant correlations included an inverse relationship between percent plump and thin kernels (r=-0.65***) and groat percentage and thin kernels (r=-0.49***), and a positive relationship between groat percent and percent plump kernels (r=0.72***). These relationships confirm the importance of kernel plumpness for economic efficiency in oat milling as less weight is lost through the removal of hulls. Purchasing grain with high kernel plumpness will result in fewer thin kernels and correspondingly a lower hull content. The result of this is a greater proportion of the larger sized milled product and fewer dollars lost through the removal of hull during the milling process or cleaning out of thin kernels prior to milling. The negative correlation between groat content and percent thin kernels is also evidence to the theory that the high test weight of OT 288 is the result of a greater proportion of hull content with a heavier weight than groat.

3.4.3 Lodging

Effects of seeding date and seeding rate on lodging were inconsistent across site years (Tables 3.12 to 3.15). In Morden 1998, the earliest seeding date resulted in the

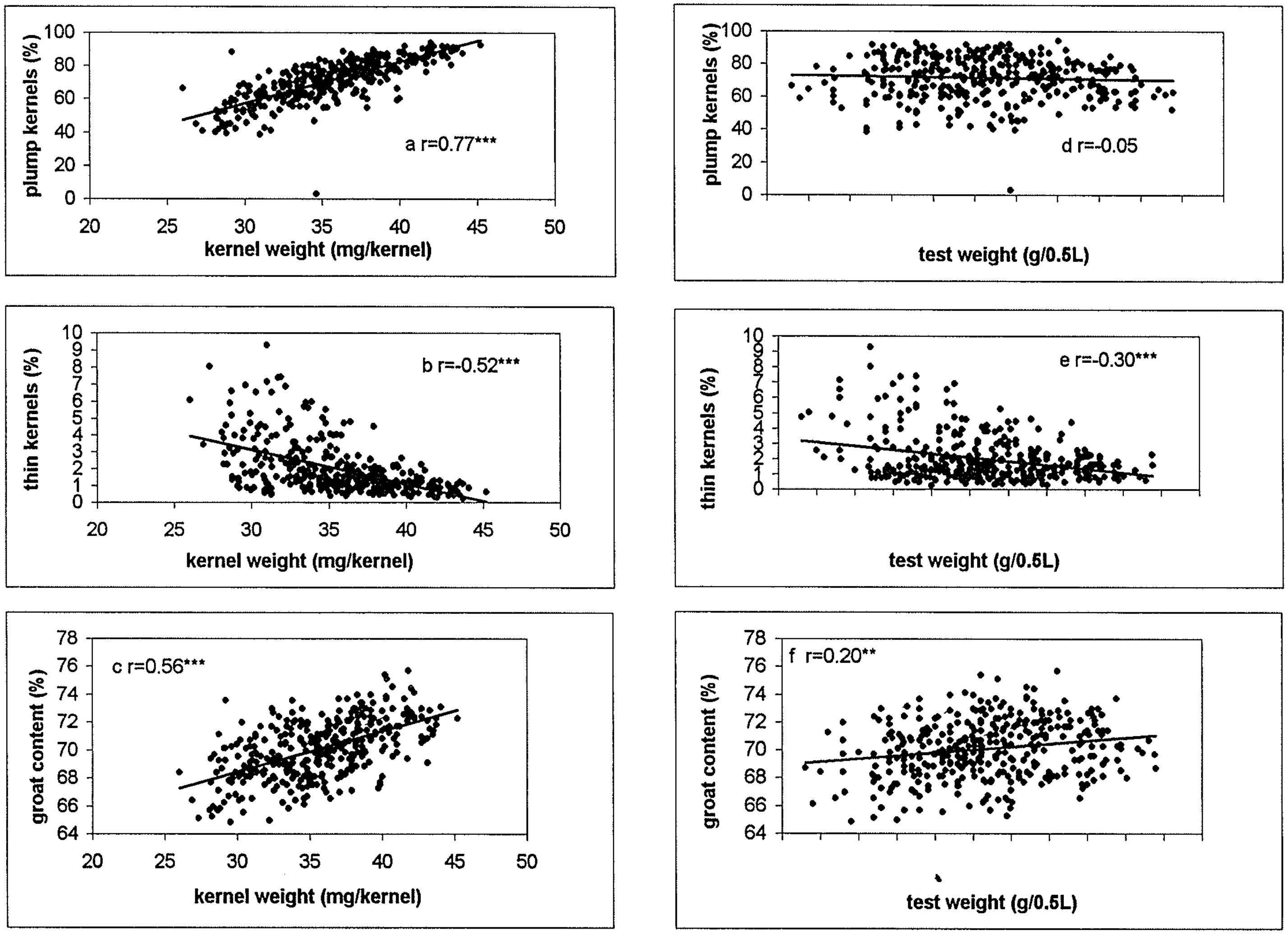

Figure 3.4 Relationship among milling quality traits across site years, cultivars, seeding dates and seeding rates: a) kernel weight vs. percent plump kernels b) kernel weight vs. percent thin kernels, c) kernel weight vs.groat percent, d) test weight vs. percent plump kernels, e) test weight vs percent thin kernels, f) test weight vs groat percent. *, **, *** significant at the p<0.05, 0.01, 0.0001 probability levels respectively.

greatest lodging while in Winnipeg 1998; the latest seeding date had the most lodging. Similar results were found in 1999. Increasing the seeding rate increased lodging at Morden 1998 and Carman 1999, but did not consistently increase lodging in Winnipeg 1998 and 1999.

OT 288 had lower levels of lodging than AC Assiniboia and AC Medallion in three out of four site years (Tables 3.12, 3.14, and 3.15). OT 288 produced a greater number of tillers per square meter and a higher HI and generally resulted in less lodging. Seeding rate, which increased panicle density, did not consistently negatively affect lodging. One might conclude from this that plant height and the cultivar's ability to partition dry matter into grain i.e. HI, and not tillering ability determined the extent of lodging. This is confirmed by the fact that the semidwarf and tall cultivars produced similar levels of dry matter at maturity (see Appendix A).

Marshall et al. (1987) suggested that the yield advantages of semidwarf oat lie in their protection of yield through the prevention of lodging. The increased yields of OT 288 in the present study were determined pre-anthesis with kernel differentiation and therefore sink establishment. The concept by Marshall et al. (1987) suggests that a yield advantage is the result of both uninhibited assimilate flow, found in an upright crop, and or less grain loss during harvesting due to an upright stand. As the yield advantage of OT 288 was determined pre-anthesis during the process of sink size establishment, this study contradicts this theory. The yield superiority of OT 288 is difficult to attribute to lodging "resistance" as higher yields of OT 288, compared with taller cultivars, were due to an increased sink size. Lodging generally occurs between anthesis and maturity, during the grain filling stage when yield potential has already been established in cereals. If the Marshall et al. (1987) theory held true, one would expect kernel weights to be correlated to lodging as lodging would disrupt assimilate flow to the filling kernels. This was not the case in this study as kernel weight was not correlated to lodging but was closely correlated to kernel number (data not shown).

It is difficult to attribute both reduced grain yield and milling quality to lodging. Lodging is thought to interfere with assimilate flow to kernel sites during grain fill. In this study, a reduced percent plump kernels and groat percent, was the result of delayed seeding and genotype, i.e. OT 288 vs. taller cultivars (Tables 3.12 to 3.15). As delayed seeding did not increase lodging, it is difficult to conclude that lodging is in any way directly related to reduced plump kernels, increased hull content, and increased thin kernels, all factors that increased with delayed seeding (Tables 3.12 to 3.15). OT 288 generally resulted in less lodging and had poorer quality than AC Assiniboia, suggesting that the greater kernel number and dry matter distribution over a larger sink size was responsible for reduced quality and not lodging. In this study it was determined that kernel weight was higher in the tall cultivars, which generally resulted in greater degrees of lodging. Therefore, one might conclude that under the conditions evaluated in this study, lodging did not negatively impact yield or quality. Conditions under which lodging might limit grain yield and milling quality include conditions of excessive moisture, high soil fertility levels lending to increased vegetative dry matter accumulation, or disease susceptibility which may affect stem and leaf tissue, i.e. crown and stem rust diseases.

3.5 Summary and Conclusions

The first objective of this experiment was to observe seeding date, seeding rate, and cultivar interactions which might allow producers to take advantage of positive interactions for yield and quality. A significant seeding date x cultivar interaction for grain milling quality was observed; percent groat and percent plump and thin kernels of AC Assiniboia were less negatively affected with later seeding than AC Medallion and OT 288. This interaction provides important information when soil or weather conditions make early seeding unavoidable and integrated pest management approaches make delayed seeding desirable. The 'very good' disease resistance in AC Assiniboia also reduces possible yield or quality reductions, which may result or be compounded by delayed seeding.

Delayed seeding date did not consistently decrease grain yield as it did not consistently negatively affect yield components. This again emphasizes the suitability of the cultivars evaluated to Manitoba soil and growing conditions and demonstrates the benefits and improvements made by Manitoba based oat breeding programs at the Cereal Research Centre, in Winnipeg, Manitoba.

Increasing seeding rates with late seeding to offset any negative effects on yield and milling quality was observed to be an ineffective strategy, as was the use of higher seeding rates at early seeding to increase yield and quality. This lack of response to the higher seeding rate was due to the inverse relationship between panicle density and the number of kernels per panicle with increasing seeding rates. Due to this inverse relationship, increasing seeding rate did not increase kernel numbers, a function of panicle density and kernels per panicle, and therefore did not increase grain yield.

Although seeding rate increases were found to not increase grain yield, they did not result in negative implications for grain yield or milling quality. This provides another useful tool for integrated pest management of wild oat and other weeds as increases in seeding rates could be used to increase crop competitiveness, without negatively affecting grain yield and quality.

The second objective of this study was to gain an improved understanding of yield limiting factors in oat and to better understand the yield physiology of oat grain yield production. OT 288 achieved higher yields than both AC Assiniboia and AC Medallion, through greater tiller and panicle densities, resulting in greater kernel production per square meter. Across environments, kernel number was highly correlated to grain yield suggesting that yield was sink limited. The greater kernel production seen in OT 288, however, was achieved at the detriment of important milling quality traits, i.e. traits that were highly correlated to kernel weight and kernel plumpness. The inverse relationship between kernel weight and kernel number observed across sight years suggests that it was the yield limiting factor for the cultivars evaluated in this study. This theory was also confirmed by the inverse relationship between kernels per panicle and kernel weight.

Limitations to the future use of OT 288 lie in its genetically poor milling quality. These limitations in quality could not be improved with earlier seeding dates or increased seeding rates observed in this study.

A definitive relationship between lodging, grain yield, and quality could not be illustrated in this study. This does not mean that under conditions conducive to lodging, ie. excessive soil fertility and high moisture, or disease, semidwarf oat cultivars could not ıproved ease of harvesting or reduced yield losses during harvesting. It does, ıean that the tools available to control wild oat in oat, i.e. increasing seeding delayed seeding will not necessarily result in increased levels of lodging and lingly not necessarily reduce grain yield and quality.

288 will be the first of many semidwarf oat cultivars developed in Western d the potential of these cultivars is evident in this study. Results of this study ıt future semidwarf cultivars may not require management different from taller, ıal cultivars. With further improvement to kernel characteristics, i.e. size ı and groat to hull ratios, through breeding, semidwarf oat have the potential to important component of oat agronomy is Western Canada.

rrently, producers are paid for grain quality based on an evaluation of test :he elevator. Further observation found this to be ineffective tool for measuring lling quality and therefore eliminating poorer quality loads of grain. This also does not provide the producer with a fair price for the actual quality Kernel weight, which can be just as easily evaluated, provided a better to other important quality traits which are critical to the efficiency and ıf the milling process.

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4. THE EFFECT OF CULTIVAR AND NITROGEN FERTILITY ON THE YIELD, YIELD COMPONENTS, AND PHYSICAL QUALITY CHARACTERISTICS OF SPRING OAT

4.1 Abstract

Five oat genotypes (AC Assiniboia, AC Medallion, CDC Boyer, OT288, and Triple Crown) were evaluated for yield and quality responses to N fertilizer at seven locations in Manitoba in 1998 and 1999. Experiments were conducted in a split plot design with cultivar as the main plot and N fertilizer as the sub plot. Four levels of ammonium nitrate fertilizer (0, 40, 80, and 120 kg/ha) were used at locations with variable levels of indigenous nitrate-N, according to soil tests. Grain yield, yield components, and physical milling quality characteristics were evaluated for all plots and grain samples. Significance of N fertilizer effects was dependent upon indigenous N fertility levels. Positive yield responses to increasing N fertilizer resulted at locations with low levels of residual N. The optimal N level for AC Assiniboia, AC Medallion, Triple Crown and OT 288 was approximately 100 kg N per ha but was found to be 90 kg N per hectare for CDC Boyer. Nitrogen x cultivar interactions for yield were observed at locations with low residual N, i.e. less than 36 kg/ha available N; AC Medallion and CDC Boyer responded negatively for grain yield to N additions beyond the optimal level due to reduced kernel number. Cultivar effects were significant for grain yield with the semidwarf OT 288 resulting in the highest yield in all locations. Nitrogen fertilizer could not effectively be used to improve physical grain quality traits; cultivar was the most important determinant of physical milling quality. At high levels of N, grain test weight was reduced. AC Assiniboia maintained consistently high quality across a diverse range of environments, while Triple Crown performed relatively poorly and erratically,

possibly due to poor stem rust resistance. OT 288 resulted in the least lodging across environments followed by AC Assiniboia and Triple Crown. Cultivar x N interactions indicated that AC Medallion and CDC Boyer resulted in increased lodging at high N rates while AC Assiniboia, Triple Crown, and OT 288 did not.

4.2 Introduction

The effect of cultivar choice and N fertility and their interactions on grain yield and quality must be evaluated in order to optimize yield and quality of newly released oat cultivars. With the potential for semidwarf oat cultivars to be released in Western Canada, observations and comparisons of semidwarf to conventional height cultivars, are necessary under varying levels of N fertility to determine appropriate N management.

N fertilizer management is a vital component of sustainable and profitable crop production with N often the most limiting nutrient to crop production, in Manitoba. Yield increases due to N fertilization have been the result of an increased number of panicles per unit area and an increase in the number of seeds per panicle (Frey, 1959b; Ohm, 1976; Brinkman and Rho, 1984). The rule of thumb in the Mid Western, United States, states that 4 kg/ha of available soil N is required to achieve a yield of 100 kg/ha (Forsberg and Reeves, 1995). This rule however, may be complicated by cultivar interactions which have been documented by several researchers (Frey, 1959b; Brown et al., 1961; Ohm, 1976; Brinkman and Rho, 1984). Evaluating newly released cultivars at varying N fertility levels will contribute to efficient use of N fertilizer and allow producers to take advantage of possible positive cultivar x N rate interactions for both yield and quality.

Moisture availability, indigenous soil nutrient levels, and cultivar lodging susceptibility mediate N responses. Due to an increased use of N fertilizer over the last 25 years (Guide to soil fertility and fertilizer use in Manitoba, 1993), residual soil nitrate levels have risen and will therefore play an important role in predicting crop N responses. Previous research has identified that environmental conditions during the growing season also play an important role in cultivar x N interactions (Lamb and Salter, 1937; Gehl et al., 1990).

The objectives of this study were to 1) observe the yield and milling quality responses of four newly released tall oat cultivars, and one unreleased semidwarf oat cultivar to N fertilizer additions across a range of locations and soil fertility levels in Manitoba, and 2) in doing so achieve the second objective of defining a set of characteristics and management practices for high yielding, high quality oat crops in Manitoba and 3) to observe whether N additions required to achieve optimum yield would result in any detrimental effects on milling quality. This study will also address the specific hypothesis of whether a semidwarf oat cultivar will result in a greater N responsiveness than traditional tall cultivars, due to the possibility of a greater sink size and improved lodging resistance.

4.3 Materials and Methods

4.3.1 Experimental Design and Field Operations

Experiments were carried out in Glenlea, Elm Creek, Morden and Silverton, Manitoba in 1998 and in Carman, Winnipeg and Silverton, Manitoba in 1999 (Table 4.1). Details of soil type, previous crop type, indigenous soil nutrient status and experimental

Table 4.1 Location, soil type and indigenous soil nutrient status, and seeding dates for cultivar x nitrogen fertility trials in 1998 and 1999.

Location Soil Type Soil Texture	Elm Creek Almasippi Clay	Glenlea Osborne Clay	Morden Altona Soil Sandy Loam	Silverton Newdale Clay Loam	Carman Denham Loam	Silverton Newdale Clay Loam	Winnipeg Riverdale Silty Clay
	1998				1999		
Previous Crop	Flax	Barley	Barley	Canola	Flax	Canola	Wheat
Estimated Available Nutrients							
	kg/ha						
Nitrate NO_3-N (to 60 cm)	121	35	144	441	36	172	29
Phosphate P_2O_5 (to 15 cm)	85	65	38	22	67	13	112
Potassium K_2O (to 15 cm)	883	1122	278	444	1044	464	992
Sulfate S (to 60 cm)	45	28	156	121	94	179	22
Sowing Date	12-May	26-May	19-May	21-May	28-May	25-May	19-May

seeding dates are provided in Table 4.1. Indigenous nitrate-nitrogen fertility levels ranged from low (~30 kg/ha) to extremely high (>400 kg/ha). A split plot design was used with cultivar as the main plot and N fertilizer rate as the subplot. Four replications were used in each experiment. With the exception of Winnipeg in 1999, the size of each sub plot was 40 m^2 (4 m x 10 m), allowing for the expression of lodging. Each plot contained 24 rows at 15 cm spacing. In Winnipeg, sub plot sizes were 8 m^2 with no separation between plots. Due to insufficient separation between plots, lodging results are not shown for Winnipeg 1999.

Five spring oat cultivars were evaluated in each experiment (OT 288 was not included in the Elm Creek 1998 location, due to a seed contamination), including AC Assiniboia, AC Medallion, CDC Boyer, OT 288, and Triple Crown (Table 4.2). AC Assiniboia, AC Medallion, CDC Boyer and Triple Crown are tall cultivars. AC Assiniboia, AC Medallion, and OT 288 had the most current resistance to crown and stem rust at the onset of these experiments. CDC Boyer has poor crown rust resistance while Triple Crown has poor stem rust and fair crown rust resistance.

Nitrogen and phosphorus fertilizer was seed placed at rates of 3 kg/ha actual N and 12 kg/ha actual P (monoammonium phosphate). Ammonium nitrate was hand scattered, immediately after plant emergence, at rates of 0, 40, 80, and 120 kg/ha (actual N).

Plots were seeded at the recommended rate of 300 viable seeds/m^2, according to the Field Guide to Crop Production (1998). Plots in Elm Creek in 1998 were sprayed with Stampede at a rate of 1.24 kg/ha on May 26, and again with Refine Extra at a rate of 0.0198 kg/ha on June 15. In Glenlea 1998, no herbicides were sprayed, as there was no

Table 4.2 Description of the five oat cultivars used in the cultivar x nitrogen fertility trials [1].

GENOTYPE	REGISTERED	HEIGHT	LODGING[2]	STEM RUST	CROWN RUST	SMUT	BYDV[3]
AC Assiniboia	yes	tall	VG	VG	VG	VG	G
AC Medallion	yes	tall	F	VG	VG	VG	P
CDC Boyer	yes	tall	G	VG	P	P	P
OT 288	no	semi-dwarf	VG	VG	VG	VG	P
Triple Crown	yes	tall	VG	P	F	G	F

[1] According to the Manitoba Seed Guide 2001.

[2] Scale based on ratings of VG=very good, G=good,F=fair, and P=poor.

[3] Barley Yellow Dwarf Virus

effective chemical control for barnyard grass in oat. No in crop herbicide was sprayed in Morden or Silverton in 1998. In Silverton 1999 Buctril M was sprayed at the recommended rate of 0.405 L/ha. In Carman and Winnipeg in 1999 weeds were controlled with the recommended rate of Roundup prior to seeding.

Environmental data, including rainfall and temperature, was collected from the Plant Science Department weather station in Winnipeg in 1999 and Environment Canada in Glenlea 1998, Elm Creek 1998, Morden 1998, Carman 1999 and Silverton in 1998 and 1999 (Tables 4.3 and 4.4).

Table 4.3 Mean monthly temperature and growing season precipitation at experimental sites in 1998

	Monthly Precipitation (mm)	Mean Monthly Temperature (°C)
	Elm Creek	
April	40	8.23
May	38	12.9
June	95	15.1
July	45	18.6
August	12	20.1
Total	230	
	Glenlea	
April	37.6	8.4
May	141	13.7
June	78.7	16.2
July	83.3	19.6
August	18.6	20.7
Total	359	
	Morden	
April	53	8.8
May	62	13.8
June	99	15.6
July	46	20.2
August	36	21.1
Total	296	
	Silverton [1]	
April	2	7.5
May	67	12.1
June	264	14.1
July	127	18.9
August	78	19.3
Total	538	

[1] Binscarth Environment Canada used for Silverton 1998 site.

Table 4.4 Mean monthly temperature and growing season precipitation at experimental sites in 1999.

	Monthly Precipitation (mm)	Mean Monthly Temperature (°C)
	Carman	
April	15	5.5
May	142	11.8
June	74	16.0
July	83	18.8
August	39	18.1
Total	353	
	Silverton [1]	
April	21	6.1
May	165	10.5
June	55	14.7
July	99	17.4
August	88	16.9
Total	428	
	Winnipeg	
April	29	7.5
May	103	13.1
June	80	17.5
July	72	20.8
August	35	19.5
Total	319	

[1] Binscarth Environment Canada used for Silverton 1999 site.

4.3.2 Grain Yield and Yield Components

Grain yield and yield components were measured on each sub plot. Plant densities were established, after full emergence, from plant counts of two-one meter lengths per sub plot. Two-one meter lengths of row were harvested from each plot at both anthesis and maturity, and were oven dried at 65 °C for at least 72 hr. and weighed to establish above ground dry matter production. In 1999, 2-1 m lengths of row were enumerated for total tiller numbers at anthesis. Panicle densities were determined, at maturity, from counts of two-one meter lengths of row per sub plot in both years. Additional yield components such as seeds per panicle, panicles per plant, and kernel numbers per m^2 were determined through calculations.

Lodging notes reported were taken post-anthesis, while the crop was still green, using a visual scale of 1 to 9. A rating of 1 indicating that 100% of the plot is standing straight up and 9 indicating that 100% of the plot is laying flat on the ground. Intermediate values are determined on the basis of plant angle and percentage of the plot affected.

Plots were harvested for grain yield using a small plot combine; at Glenlea 1998, Morden 1998, and Carman 1999, sites were harvested with a Wintersteiger combine, and at Elm Creek 1998 and Silverton 1998 were harvested with a Hege combine. Eight and 10 rows were harvested with the Hege and Wintersteiger, respectively for grain yields. At Winnipeg 1999 and Silverton 1999, plots were hand harvested and threshed using a Hege combine. Grain was cleaned using either a seed blower (Bill's Welding, Pullman, Washington) in 1998 or Clipper in 1999. Grain yields were not adjusted for moisture content however moisture levels were determined to be consistent among the grain samples.

4.3.3 Physical Milling Quality Analysis

Milling quality attributes were tested from one randomly drawn sample of grain from each sub plot. Physical milling quality traits assessed included test weight (g/0.5L), kernel weight (mg/kernel), groat and hull content (percent), and plump and thin kernels (percent).

Test weight was determined as the weight of grain in a 0.5 L volume container after passing through a cox funnel and levelled using a roller.

Kernel weight was determined by the number of grains in a 10 gram sample (double and dehulled grains were removed) and converted to it's 1000 grain weight equivalent.

Groat and hull content were calculated as a percentage, using a 70 gram whole oat sample passed through a Codema laboratory hulling machine (LH 5095, Codema Incorporated, Vancouver B.C.) (see Appendix A.2 for settings and instructions).

Percent plump grain was determined by the weight of grain from a 20 g sample that did not pass through a 2.4 mm x 19 mm screen (double and dehulled grains were removed prior to sieving). Percent thin grain was determined by the weight of grain from a 20 g sample that passes through a 0.8 mm x 19 mm screen. The two sieve sizes were placed one on top of the other with the larger sieve size on top. The sieves were then lined up with the sieve slots facing vertically in the same direction and the sample was shaken from side to side ten times. The grain remaining on top of the 2.4 mm x 19 mm screen was then weighed and considered plumps, while the grain that fell through the 0.8 mm x 19 mm screen was weighed and considered thins.

4.3.4 Statistical Analysis

Data from all site years was evaluated for homogeneity of error variances using a Bartlett's test. Due to heterogeneity of error variances, the four site years were analyzed individually using an analysis of variance (see Appendix B.1). Fisher's least significant difference test was used when the ANOVA F statistic was significant ($P<.05$).

4.4 Results and Discussion

4.4.1 Low Residual N Sites

4.4.1.1 Grain Yield and Yield Components

Soils at Glenlea 1998, Carman 1999, and Winnipeg 1999 were found to have 36 kg or less available nitrate-N at seeding (Table 4.1) and were, therefore, considered low residual N sites.

Cultivar effects were significant for yield with OT 288 yielding the highest and CDC Boyer yielding the lowest at all three sites (Tables 4.5 to 4.7). Humphreys et al. (1994a) found a similar significant cultivar effect on yield in a Quebec study evaluating four oat cultivars.

N effects were significant for grain yield at low N locations; N increased grain yield up to the 80 kg/ha application rate after which yield began to decline (Tables 4.5 to 4.7). As stated by Forsberg and Reeves (1995) and Soper et al. (1971) fertilization management was dependent on the existing soil nutrient level, i.e. the indigenous soil nitrate. These results agree with the findings of Brown et al. (1961) who found that the greatest increases in grain yield with N fertilization, occurred between the low to intermediate N levels.

Figure 4.1 illustrates N responses at Glenlea 1998, Carman 1999, and Winnipeg 1999. Nitrogen levels displayed on the x axis are equal to indigenous N according to soil tests plus fertilizer N added at emergence. Grain yield of all cultivars responded up to the 80 kg/ha N fertilizer rate. CDC Boyer was the exception at Glenlea in1998.

Table 4.5 The effect of cultivar and nitrogen fertilizer rate on yield, yield components, and physical milling quality traits of oat cultivars grown at Glenlea, Manitoba 1998 (low residual N site).

Main Effect		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No. per square meter	Panicle No. per square meter	Kernels/ panicle	HI%	Lodging(1-9) [1](7.9.98)	Test Wt. (g/0.5L)	Plumps %	Thins %	Groat %
Cultivar												
OT 288		4809a	30.2c	20753 a	184a	90a	60.5a	1.0c	265ab	45.6c	8.0ab	68.7d
AC Assiniboia		4054ab	38.5a	13471b	158ab	69cd	52.9ab	1.3bc	263b	73.2a	1.6d	72.0a
AC Medallion		3895bc	34.9b	14202b	143b	79b	48.8ab	1.8b	266a	56.0b	4.4cd	71.1b
CDC Boyer		3147c	33.8b	11890b	141b	67d	46.4b	2.6a	245c	52.4bc	5.2bc	70.3c
Triple Crown		3483bc	30.9c	14678b	147b	78bc	44.8b	1.0c	237d	23.3d	10.0a	64.8e
lsd (0.05)		785	2.0	3991	31	10	13.6	0.7	3	7.5	3.1	0.7
N Rate												
0		2985b	35.3a	8500b	142c	61b	53.7ab	1.0c	259a	62.8a	2.4c	69.3a
40		4188a	34.1ab	12491a	146bc	86a	56.4a	1.1c	259a	48.1b	5.0b	69.6a
80		4222a	32.9bc	13133a	160ab	82a	50.4ab	1.6b	253b	45.1b	7.2a	69.4a
120		4114a	32.2c	12964a	171a	77a	45.5b	2.6a	251b	44.3b	8.7a	69.2a
lsd (0.05)		370	1.7	1112	15	11	8.5	0.4	4	3.9	1.8	0.7
Source of Variation		ANOVA (P>F)										
	df											
Cultivar	4	0.0063	0.0001	0.0046	0.0561	0.0025	0.0571	0.0013	0.0001	0.0001	0.0006	0.0001
N Rate	3	0.0001	0.0041	0.0001	0.0014	0.0002	0.0817	0.0001	0.0001	0.0001	0.0001	0.6408
CxN	12	0.0150	0.2731	0.0035	0.1169	0.4712	0.8698	0.0001	0.1368	0.4299	0.0693	0.0641
CV%		15.0	8.1	14.8	15.4	22.6	25.9	43.7	2.4	12.4	48.3	1.5

[1] Indicates date of lodging assessment.

a-d means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*CxN refers to cultivar (C) and notrogen rate (N).

Table 4.6 The effect of cultivar and nitrogen fertilizer rate on yield, yield components, and physical milling quality traits of oat cultivars grown at Carman, Manitoba 1999 (low residual N site).

Main Effect	Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No. per square meter	Panicle No. per square meter	Kernels/ panicle	HI%	Lodging(1-9) [1](11.8.98)	Test Wt. (g/0.5L)	Plumps %	Thins %	Groat %
Cultivar											
OT 288	4391a	37.6c	11811a	263a	46b	46.1a	1.0d	245a	72.2b	1.4b	68.5b
AC Assiniboia	3832b	43.3a	8882b	213b	42bc	38.6b	2.0c	239b	90.4a	0.8c	71.6a
AC Medallion	3503c	37.4c	9371b	212b	45b	40.2b	4.9a	240ab	76.1b	1.9a	69.2b
CDC Boyer	3065d	42.5a	7245c	213b	35c	35.9b	3.8b	236b	89.4a	0.6cd	71.6a
Triple Crown	3672bc	40.5b	9046b	168c	55a	39.3b	1.0d	239b	64.6c	0.5d	66.7c
lsd (0.05)	304	2.0	962	27	7	4.5	0.8	5	5.5	0.2	0.7
N Rate											
0	2823c	41.0a	6929d	191b	38c	40.1a	1.0c	243a	80.2a	0.7b	68.6c
40	3766b	41.1a	9252c	211ab	45b	40.5a	1.1c	241ab	80.7a	0.7b	69.4b
80	4300a	39.8b	10960a	227a	50a	41.2a	3.7b	239b	76.4b	1.3a	70.1a
120	3891b	39.5b	9940b	227a	45b	38.1a	4.5a	234c	77.9ab	1.5a	70.1a
lsd (0.05)	242	0.9	618	24	5	3.5	0.6	3	3.7	0.5	0.5

Source of Variation	df	Yield	Kernel Wt.	Kernel No.	Panicle No.	Kernels/ panicle	HI%	Lodging	Test Wt.	Plumps	Thins	Groat
		ANOVA (P>F)										
Cultivar	4	0.0001	0.0001	0.0001	0.0001	0.0008	0.0052	0.0001	0.0752	0.0001	0.0001	0.0001
N Rate	3	0.0001	0.0005	0.0001	0.0068	0.0001	0.5273	0.0001	0.0001	0.0590	0.0007	0.0001
CxN	12	0.0035	0.0001	0.0004	0.0031	0.0922	0.1559	0.0001	0.3980	0.0031	0.0035	0.0011
CV%		10.1	3.4	10.3	17.5	16.6	13.3	33.1	2.1	7.1	67.2	1.2

[1] Indicates date of lodging assessment.

a-d means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*CxN refers to cultivar (C) and notrogen rate (N).

Table 4.7 The effect of cultivar and nitrogen fertilizer rate on yield,yield components, and physical milling quality traits of oat cultivars grown at Winnipeg, Manitoba 1999 (low residual N site).

Main Effect		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No. per square meter	Panicle No. per square meter	Kernels/ panicle	HI%	Test Wt. (g/0.5L)	Plumps %	Thins %	Groat %
Cultivar											
OT 288		4330a	33.9bc	12814 a	236a	54b	61.7a	251a	60.0b	1.7ab	67.6ab
AC Assiniboia		4097a	37.8a	10940b	204b	55b	60.7a	247ab	77.1a	0.8c	70.3a
AC Medallion		3418b	31.9c	10719b	184bc	60b	54.7a	247ab	63.6b	1.9a	66.8ab
CDC Boyer		3427b	37.0ab	8575c	166c	56b	55.3a	240b	83.4a	0.7c	66.5ab
Triple Crown		3936a	33.7bc	11717ab	162c	73a	51.0a	245ab	35.2c	1.2bc	64.1b
lsd (0.05)		407	3.8	1540	27	8.5	11.8	10	6.6	0.6	8.00
N Rate											
0		2257c	35.3a	6377c	144c	46b	61.2a	249a	65.5a	1.1b	67.5a
40		3731b	35.6a	10530b	177b	61a	53.5b	247a	63.8ab	1.1b	67.7a
80		4665a	35.9a	13795a	214a	67a	57.4ab	246a	63.7ab	1.3ab	67.7a
120		4652a	34.9a	13418a	224a	64a	55.8ab	242b	62.0b	1.5a	68.4a
lsd (0.05)		361	0.8	1026	16	7	6.8	4	2.9	0.3	1.0
Source of Variation	df	ANOVA (P>F)									
Cultivar	4	0.0030	0.0006	0.0022	0.0013	0.0053	0.3053	0.2109	0.0001	0.0085	0.0010
N Rate	3	0.0001	0.4064	0.0001	0.0001	0.0001	0.0764	0.0030	0.0939	0.0525	0.2088
CxN	12	0.0001	0.8339	0.0001	0.0001	0.0176	0.1348	0.1141	0.0156	0.4029	0.1063
CV%		18.2	4.6	17.9	16.1	23.8	23.2	3.1	8.8	52.1	2.7

a-d means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*CxN refers to cultivar (C) and notrogen rate (N).

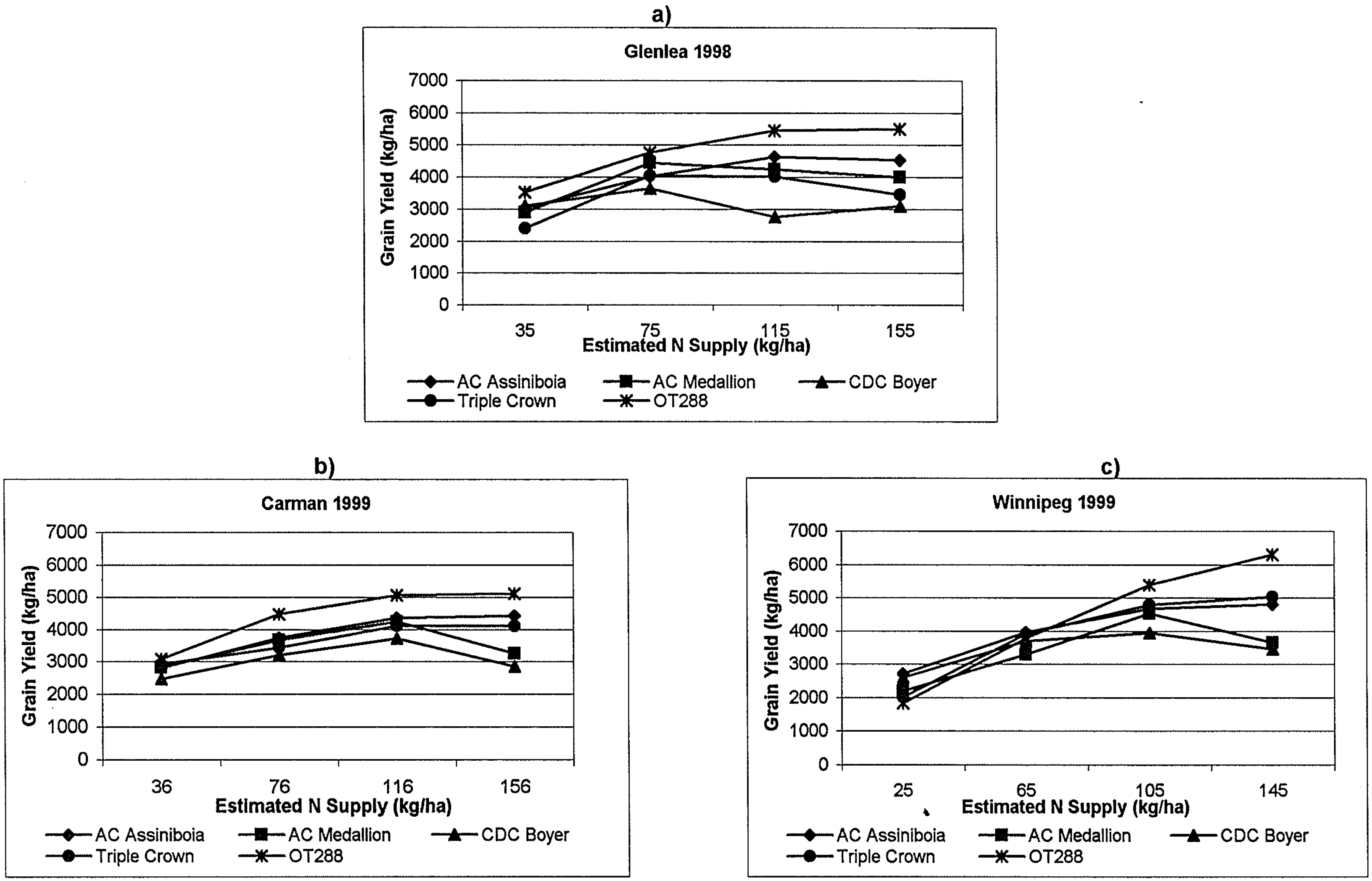

Figure 4.1 Mean grain yield (kg/ha) at low residual N site years a) Glenlea 1998, b) Carman 1999, c) Winnipeg 1999, where C x N interactions were observed ($p>0.05$).

Significant cultivar x N interactions for grain yield were observed at experimental sites with low residual N levels (Tables 4.5 to 4.7). In similar Manitoba studies Mohr et al. (unpublished) found that 'AC Assiniboia' and 'AC Ronald' did not result in a cultivar x N interaction while Knaggs (2002) found similar results with 'Triple Crown' and 'AC Ronald'. Several other studies however, have documented cultivar x N interactions for grain yield (Brinkman and Rho, 1984, Brown et al., 1961, Frey 1959b, Ohm, 1976).

The response curves and equations for each cultivar across low N site years revealed cultivar x N interactions and illustrated the non linear relationship between N and grain yield (Figure 4.2). For example, AC Assiniboia, Triple Crown and AC Medallion responded similarly to estimated N supplies of approximately 120 kg/ha but at this point cultivar differences became apparent. First, the yield of AC Assiniboia was maintained beyond 120 kg/ha, while the yields of Triple Crown and AC Medallion began to decline; AC Medallion exhibited a sharper decline. The flatter response curve of CDC Boyer (Figure 4.2) illustrated a relative lack of response to fertilizer N additions. Second, the response curve of OT 288 indicated a greater responsiveness to N additions than all of the tall cultivars. At estimated N supplies of 120 kg/ha, the yields of OT 288 were up to1000 kg/ha higher than both AC Assiniboia and Triple Crown, which reached their peak grain yield at N additions in this range. OT 288 continued to respond to an estimated N supply beyond 120 kg/ha but appeared to level off at approximately 130 kg/ha.

These results suggest that N applications beyond the optimum for AC Medallion, CDC Boyer and Triple Crown can result in more negative effects on grain yield than AC

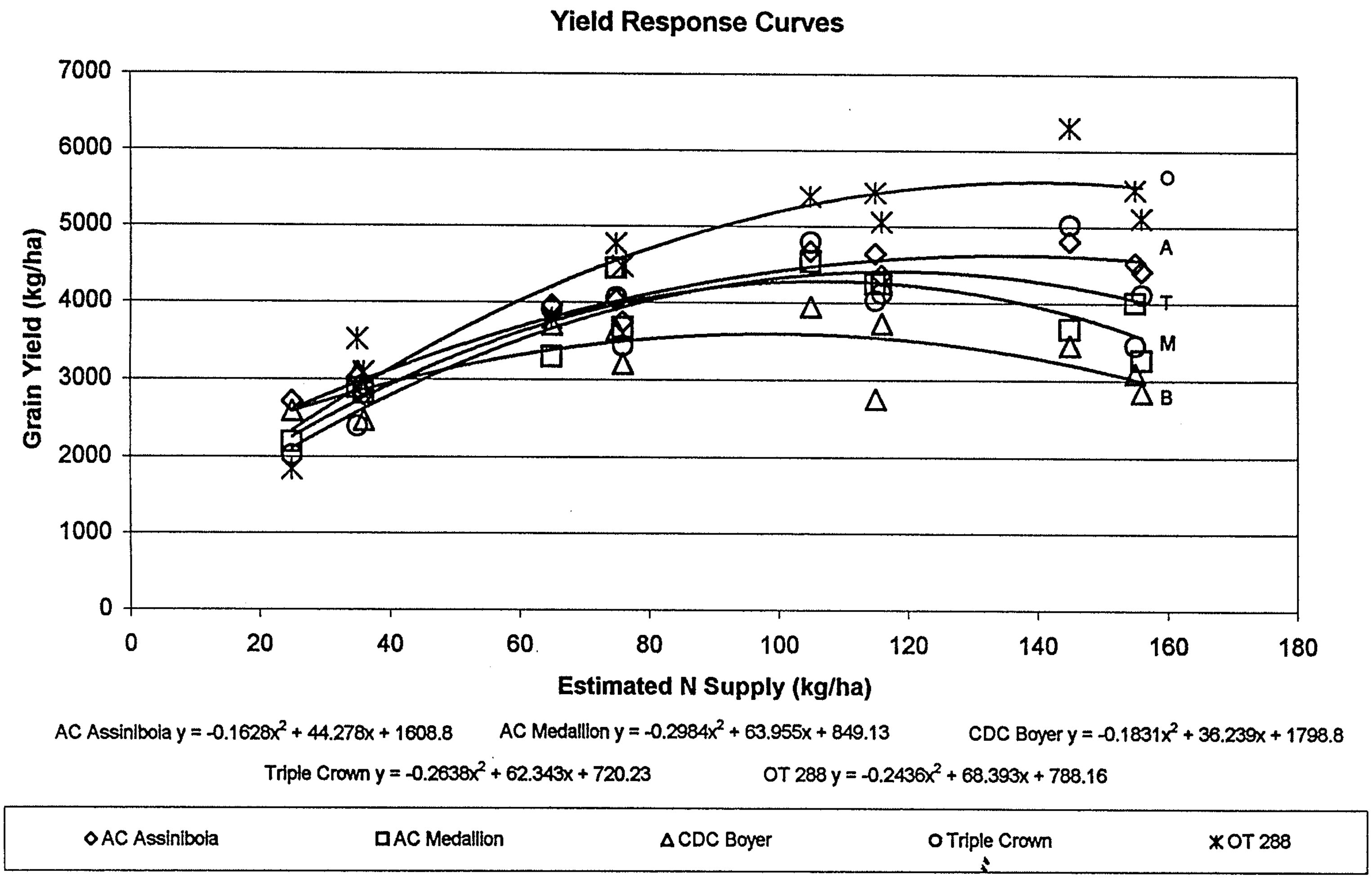

Figure 4.2 Quadratic response curves for cultivars grown at low residual N sites for mean grain yield (kg/ha).

Assiniboia and OT 288. This kind of over-fertilization also results in the wasted cost of N fertilizer that is not being used to improve gain yield.

The optimum level for N fertilizer additions for AC Assiniboia, AC Medallion, and Triple Crown was observed from the curve to be approximately 100 kg/ha estimated N supply. CDC Boyer was observed to respond up to an estimated N supply of 90 kg/ha. Assuming fields would have an average of 30 kg/ha available N in the spring this would result in N application rates of approximately 70 kg/ha for AC Assiniboia, AC Medallion, and Triple Crown.

The above optimal N levels are substantially lower than those that would be derived from the American rule of thumb as stated by Forsberg and Reeves (1995). Using their rate of 4.2 kg of N to produce 100 kg of grain yield, this would result in an N rate of 168 kg/ha to produce a yield of 4000 kg, which was reached at the optimal N level of 100 kg N/ha for AC Assiniboia.

The greater N responsiveness of OT 288 supports the findings of Anderson and Maclean (1989) where the semidwarf 'Echidna' had an increased responsiveness to N fertilizer in comparison to several tall cultivars evaluated. On the other hand, Marshall et al. (1987) observed similar N fertilizer responses for a tall and semidwarf oat cultivar, in Pennsylvania as did Meyers et al. (1985) in Minnesota. Results of the present study also support the conclusions of Frey (1959b), Brown et al. (1961), Ohm, (1976), and Brinkman and Rho (1984), who emphasized the importance of evaluating new cultivars at varying N fertility.

The effect of improved productivity due to increased N can be explained by the relationships among panicle numbers and kernels per panicle in response to N. Frey (1959b), Ohm (1976), and Brinkman and Rho (1984) attributed yield increases from N fertilizer to an increased number of productive panicles per unit area and an increase in the number of kernels per panicle. In the present study, N significantly increased panicle numbers at all three site years ($p<0.01$) (Tables 4.5 to 4.7). Panicle numbers were increased up to the highest N fertilizer level at Glenlea and Winnipeg, while at Carman panicle numbers remained constant from the 80 kg/ha N treatment to the 120 kg/ha N. OT 288 responded positively for panicle number at all N rates in all three site years (Figure 4.3). This higher panicle number accompanied by the fact that OT 288 had similar or higher numbers of kernels per panicle resulted in its higher productivity than the tall cultivars.

OT 288 resulted in significantly higher kernel numbers per m^2 ($p<0.01$) (Figure 4.4). OT 288 had a greater number of panicles per square meter (Figure 4.3) and a higher or equal number of kernels per panicle, relative to the tall cultivars (Tables 4.5 to 4.7). Therefore, the increased yield of the semidwarf was due to a higher overall productivity and increased sink size achieved through greater tillering potential leading to a greater production of panicles and the maintenance of kernel numbers per panicle.

Higher yields of OT 288 were not the result of an increased HI; as OT 288 had a significantly higher HI at only Carman in 1999, while yields were higher in all 3 site years (Table 4.5 to 4.7). These results differed from Section 3 where the HI of OT 288 was higher than the tall cultivars. It should be noted that some exceptionally high HI

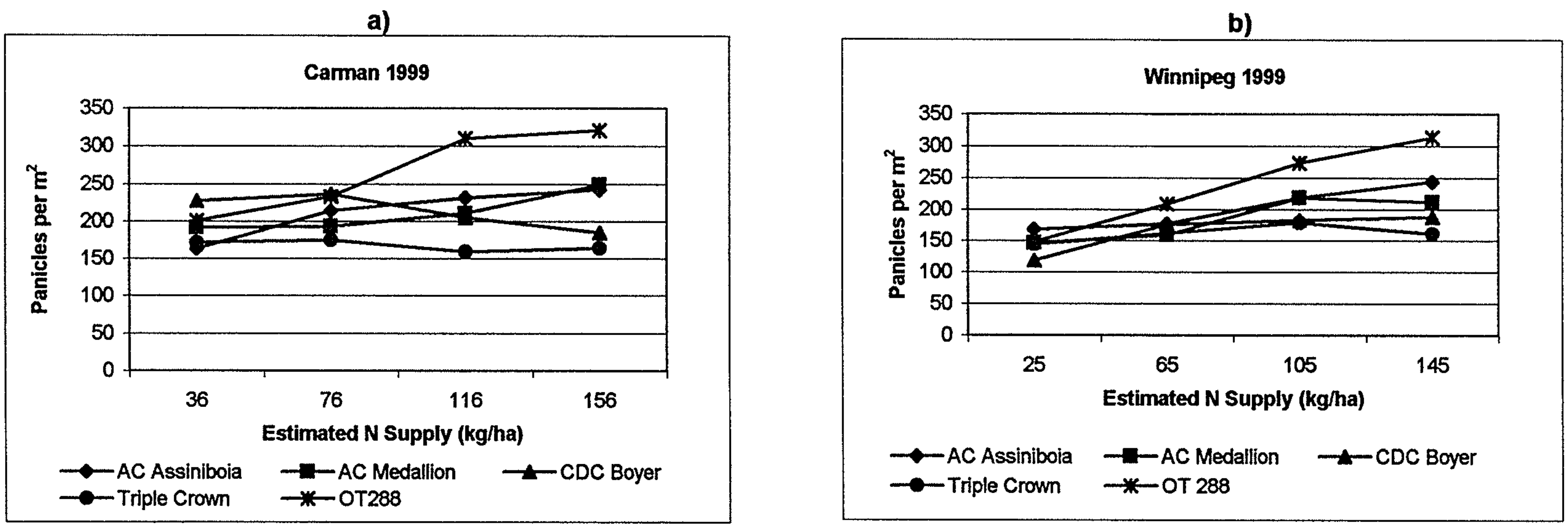

Figure 4.3 Mean panicle number per m^2 at low residual N site years a) Carman 1999, b) Winnipeg 1999.

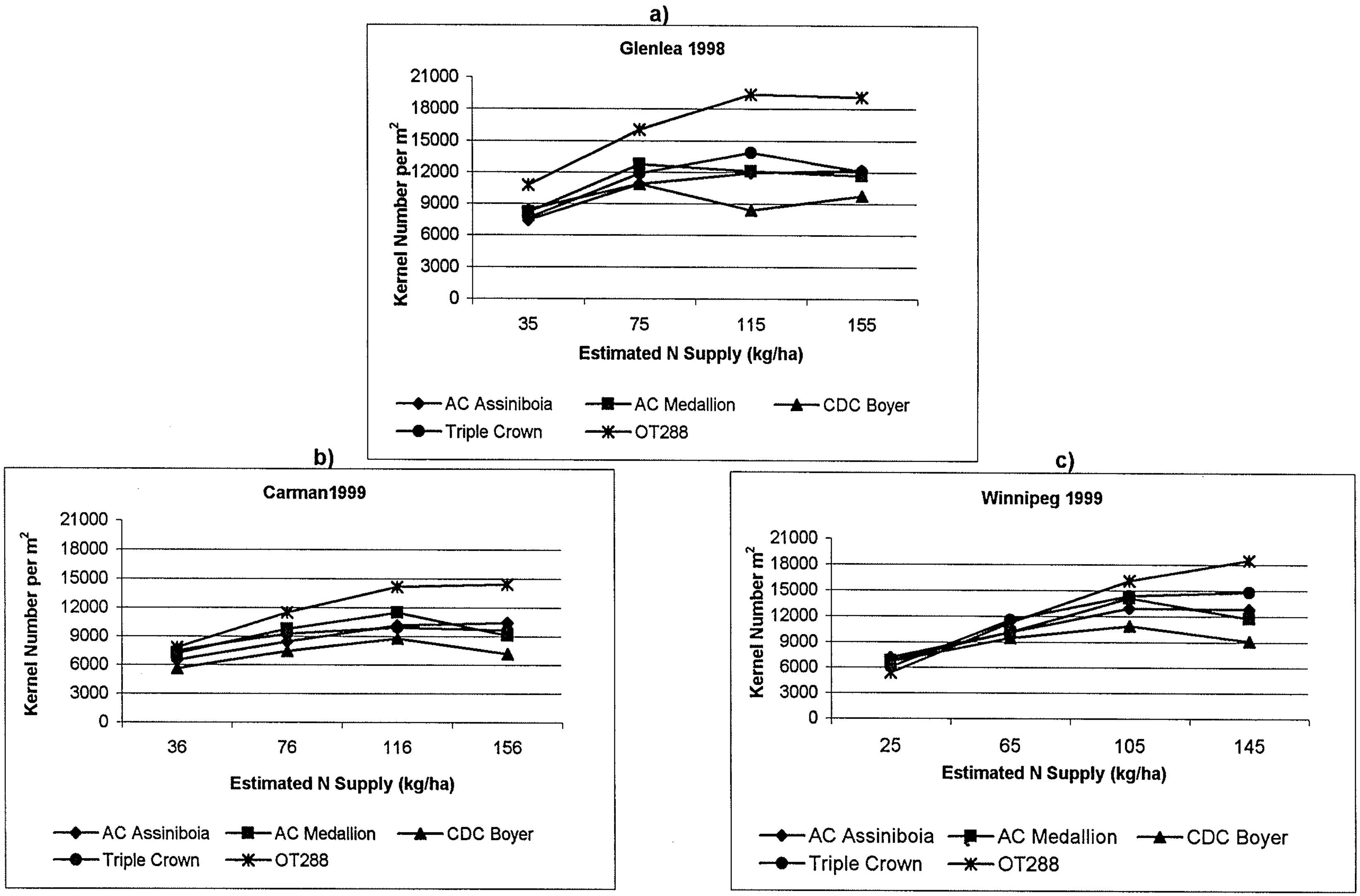

Figure 4.4 Mean kernel number per m^2 at low residual N site years a) Glenlea 1998, b) Carman 1999, c) Winnipeg 1999.

values were observed at Glenlea 1998 and Winnipeg in 1999, suggesting that leaf loss, prior to dry matter harvest, may have occurred.

Cultivar significantly affected kernel weight, kernel number, panicle number, and kernels per panicle ($p<0.01$) (panicle number at Glenlea $p<0.0561$) (Tables 4.5 to 4.7). AC Assiniboia and CDC Boyer demonstrated high kernel weights across sites and N rates, while OT 288 resulted in lower kernel weights.

Significant N effects for kernel weight, in Glenlea and Carman, were negative (Tables 4.5 and 4.6). This was similar to the study by Brinkman and Rho (1984) where cultivars that had increased yield with increasing N fertility also saw reductions in kernel weight.

Several significant cultivar x N interaction effects were observed, for kernel number at Glenlea 1998 ($p<0.01$), for kernel weight, kernel number, and panicle number at Carman in 1999 ($p<0.01$), and for kernel number, panicle number and kernels per panicle at Winnipeg in 1999 ($p<0.05$) (Tables 4.5 to 4.7). Kernel numbers demonstrated a similar pattern to grain yield with interaction effects observed at the high N rates (Figure 4.4). This suggests that similar to the previous experiment, kernel number and therefore sink size is highly correlated to grain yield and therefore yield is sink limited. The panicle numbers of OT 288 responds positively to N fertility while panicle numbers of the taller cultivars are maintained or as is the case with AC Assiniboia, increase slightly (Figure 4.3).

4.4.1.2 Physical Milling Quality Characteristics

Test weights were higher at the Glenlea 1998 site vs. the Carman 1999 and Winnipeg 1999 sites (Tables 4.5 to 4.7). At Glenlea, percent plump kernels were lower than Carman and Winnipeg (Tables 4.5 to 4.7, Figure 4.5). This suggests the high test weight at Glenlea was achieved through the second mechanism for achieving high test weight discussed in Section 3.4.2, where a greater number of thinner sized kernels with a greater packing efficiency resulted in higher test weight. Glenlea 1998 also resulted in a high percentage of thin kernels, again supporting this theory. A high test weight and lower percentage of plump kernels, across cultivars and similar N rates at Glenlea, as in other site years, suggests that other factors played a role in determining test weight, possibly soil type or soil moisture conditions. Although the Glenlea site was seeded two days earlier than Carman, Carman resulted in higher plump kernels and fewer thin kernels (Tables 4.5 and 4.6).

Cultivar effects were significant for test weight at Glenlea 1998; AC Assiniboia, AC Medallion, and OT 288 resulted in high test weights, i.e. over 260 g/0.5 L, while CDC Boyer and Triple Crown had comparatively low test weights (Tables 4.5). Cultivar significantly affected groat percentage and percent plump and thin kernels at all low N locations; AC Assiniboia and CDC Boyer produced higher percentages of groat and plump kernels, and lower percentages of thin kernels (Tables 4.5 to 4.7). Groat percentage was largely determined by cultivar, as levels remained relatively constant across N levels. AC Assiniboia demonstrated high groat percentages, in the range of 70 to 72%, while Triple Crown had generally low groat percentages, in the range of 64 to 66%. AC Assiniboia maintained high quality across environments and N rates while Triple

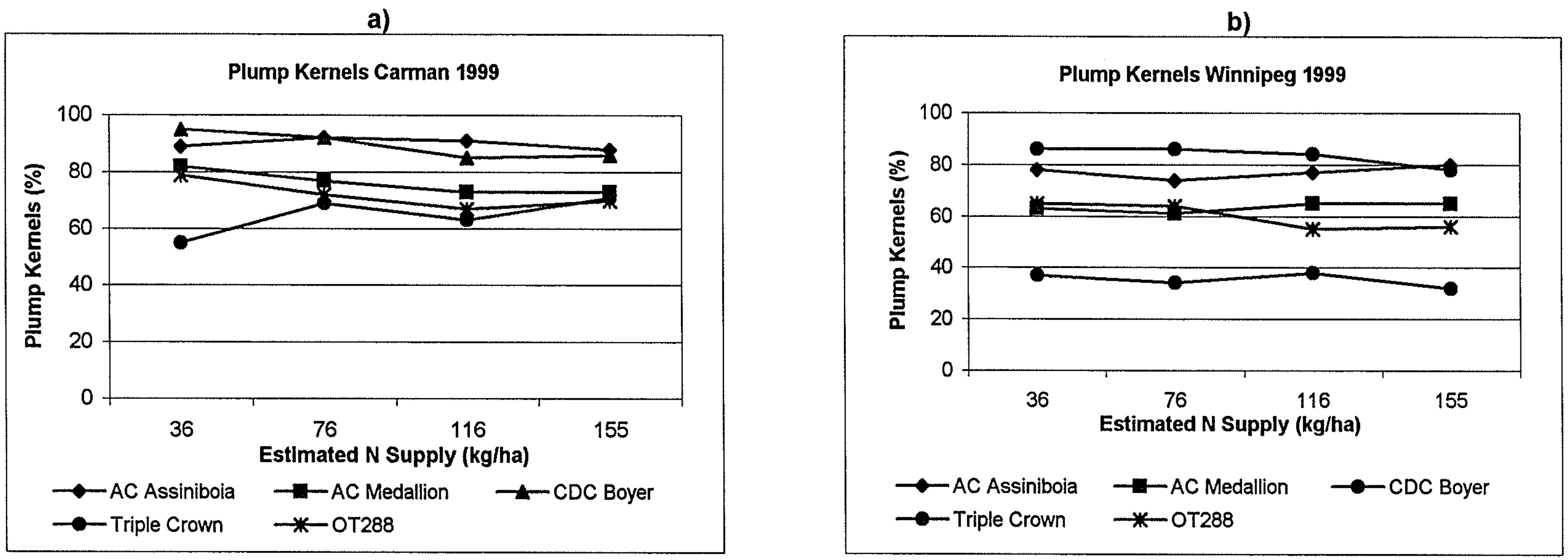

Figure 4.5 Mean plump kernels (%) at low residual N sites years a) Carman 1999, b) Winnipeg 1999.

Crown responded unpredictably and poorly. This may be due to Triple Crown's susceptibility to prevalent races of stem rust, and its susceptibility to blast, both of which were observed in the field but were not evaluated. These factors may have negatively affected kernel filling and therefore related quality traits. These results confirm Humphreys et al. (1994a) theory that choosing the correct cultivar is crucial for the production of high quality oat grain.

Nitrogen fertilizer effects were significant for test weight at all three sites, with N decreasing test weight. Test weights were highest at the 0 and 40 kg N/ha rates and declined at the 80 and 120 kg N/ha. These results differed from a study by Humphreys et al., (1994a) in Quebec, which found no significant N effects on test weight. Percent plump kernels were found to be highest at the lowest N application rate in all site years agreeing with the study by Zhou et al. (1998) in Australia where N additions between 0 to 100 kg/ha did not affect the number of plump kernels. Higher N levels resulted in a greater sink size and therefore a greater kernel "area" for dry matter distribution, resulting in smaller sized kernels.

Nitrogen effects were significant for groat percentage at the Carman location, where groat percentages were higher at the 80 and 120 kg N/ha rates, similar to the study by Humphreys et al. (1994a) where the only significant N effect on milling quality was a slight increase in groat yield. This suggests that N fertilizer could not consistently or reliably be used as an effective tool to increase groat percentage. Peltonen-Sainio (1997) also found similar inconsistent effects of N on groat yield. This seems logical as increasing N fertilizer resulted in a greater number of panicles per unit area leading to dry matter distribution over a larger number of kernels and therefore smaller kernels with comparatively smaller groat content.

The relationships among N fertility and milling quality, i.e. test weight, percent plump kernels and groat percentage suggest that while increasing N increases grain yield it also decreases quality. Therefore, it appears that a balance between maximum yield and quality is the challenge in N management for oat, as it is with most crops.

A single interaction effect was observed for percent plump kernels in Winnipeg ($p<0.05$) (Table 4.7 and Figure 4.5). While in Carman, significant interaction effects were observed for percent plump and thin kernels and groat percentage ($p<0.01$) (Table 4.6 and Figure 4.5). At both Winnipeg and Carman, percent plump kernels of OT 288 decreased beyond 0 kg/ha N fertilizer. This decrease corresponds to a greater number of panicles produced at the 40, 80 and 120 kg N/ha rates vs. the 0 kg N/ha rate (Figure 4.3). For example at the 0 kg N/ha rate in Carman, OT 288 produced approximately 200 panicles/m^2 compared to the 320 panicles/m^2 at the 120 kg N/ha rate. This results in dry matter distribution over a significantly greater sink size resulting in smaller and therefore less plump kernels.

4.4.1.3 Lodging

Cultivar effects on lodging score (prior to harvest) were significant at Glenlea in 1998 and Carman in 1999 (Tables 4.5 and 4.6). At both sites CDC Boyer resulted in greater lodging followed by AC Medallion at Carman in 1999. OT 288 had significantly lower lodging scores at both sites followed by AC Assiniboia and Triple Crown. Brown et al. (1980) found similar results with the semi dwarf 'OT 207', which demonstrated superior lodging resistance to the tall cultivars 'Rodney' and 'Hudson'.

Nitrogen effects were significant for lodging score at Glenlea in 1998 Carman in 1999 where the 80 and 120 kg/ha N rates had significantly higher lodging scores than the lower N rates (Tables 4.5 and 4.6). Brinkman and Rho (1984) also observed a significant N fertility effect on lodging with three oat cultivars in Wisconsin. This demonstrates that where additional N fertilization is required, applying the optimum level of N (estimated N supply of 115 kg/ha) can prevent lodging; beyond this N level, the risk of lodging is increased.

Cultivar x N effects were significant for lodging at Glenlea in 1998 and Carman in 1999, (Figure 4.6) contrary to the aforementioned study by Brinkman and Rho (1984). Similar to the high N sites where an interaction effect was seen, AC Medallion and CDC Boyer resulted in greater lodging with increasing N. Differences among cultivars were greatest at the 120 kg/ha N application rate, and at the 80 kg/ha N rate in Carman in 1999.

OT 288 stood out as the superior yielding cultivar and had low lodging scores although yield was the result of increased sink size. AC Assiniboia and Triple Crown again stood out under higher levels of N application as having less lodging than CDC Boyer and AC Medallion, suggesting they are better suited for Manitoba in terms of lodging "resistance". These results were contrary to studies by Knaggs (2002) and May and Mohr (unpublished) who evaluated several oat cultivars in Manitoba and found that lodging was determined by N levels and not cultivar.

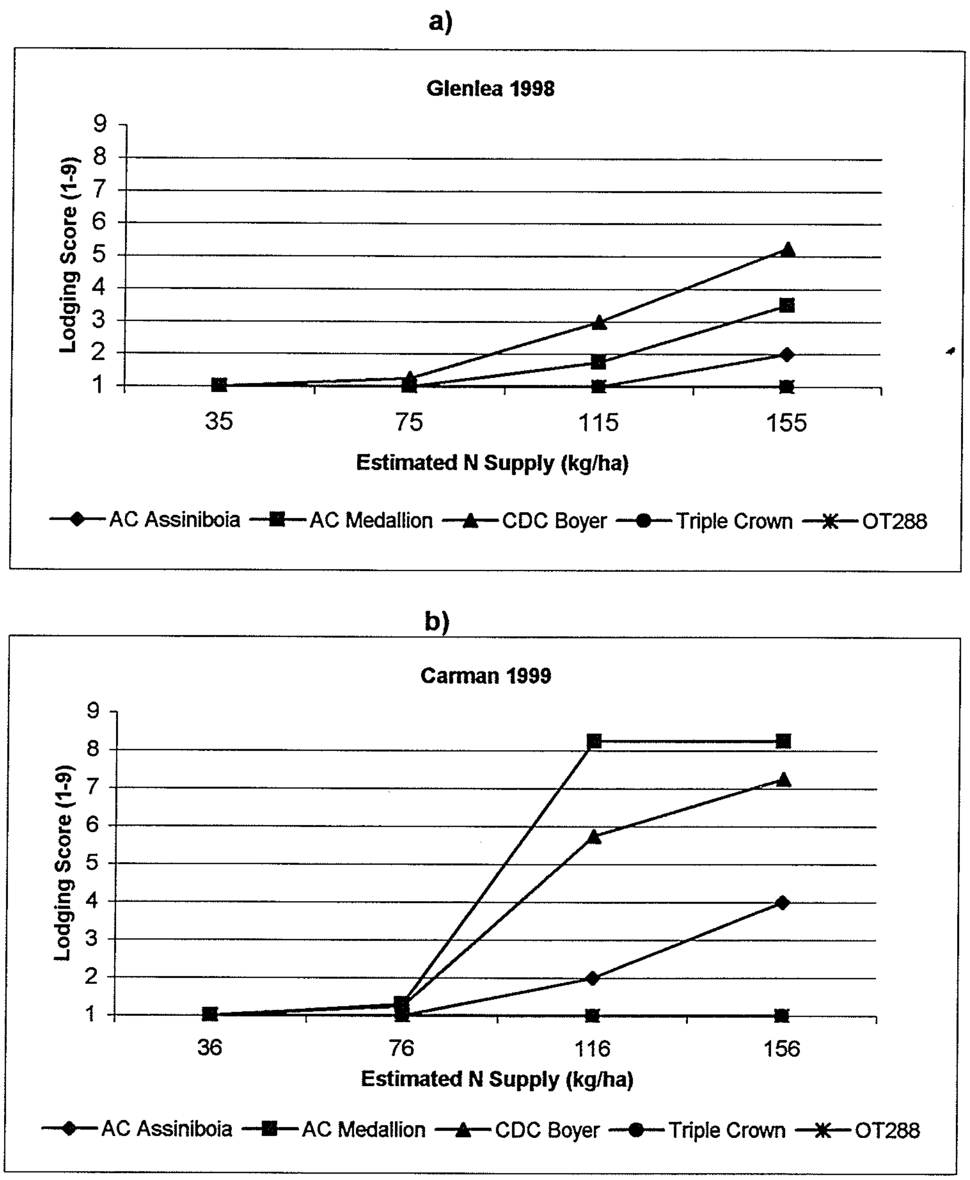

Figure 4.6 Mean lodging scores at a) Glenlea 1998 and b) Carman 1999; locations where C x N interactions were observed.

4.4.2 High Residual N Sites

4.4.2.1 Yield and Yield Components

The Elm Creek 1998, Morden 1998, and Silverton 1998 and 1999 sites were found to have greater than 100 kg/ha of available nitrate-N at seeding and were, therefore, designated high residual N sites (Table 4.1). As expected response curves were relatively flat, as N did not significantly increase grain yield at these sites (Tables 4.8 to 4.11). However, it should be noted that N did not decrease yield at three out of four sites; yield was only significantly ($p < 0.0018$) negatively affected at Elm Creek 1998 (Table 4.8). Therefore when high N levels cannot be avoided yield reductions may not result. Yield components were unaffected by N fertilizer application at all locations, with the exception of a negative kernel weight response at Silverton in 1999 (Table 4.11).

Under conditions highly conducive to lodging (i.e. Silverton 1998, where available nitrate levels were >400 kg/ha prior to fertilizer application), OT 288 produced grain yields in excess of 4000 kg/ha while the tall cultivars yielded less than 3000 kg/ha. At this same location, OT 288 resulted in a mean lodging rating of 1.1 compared to 7.9 for the lowest yielding cultivar CDC Boyer.

Cultivar effects were significant for grain yield at all four locations, with OT 288 yielding the highest at the three locations at which it was evaluated. These results were similar to those found in the previous experiment where the higher yields of OT 288 were due to consistently high kernel numbers, even under high N conditions. This demonstrates the yield advantages of semidwarf oat found under high N environments, as stated by Marshall et al. (1987).

Table 4.8 The effect of cultivar and nitrogen fertilizer rate on yield, yield components, and physical milling quality traits of oat cultivars grown at Elm Creek, Manitoba 1998 (high residual N site).

Main Effect		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No. (per square meter)	Panicle No. (per square meter)	Kernels/ panicle	HI%	Lodging(1-9) [1](31.8.98)	Test Wt. (g/0.5L)	Plumps (%)	Thins (%)	Groat (%)
Cultivar												
AC Assiniboia		4057ab	32.0ab	12697a	219a	60ab	34.6a	3.5ab	219b	57.9b	5.1a	71.5b
AC Medallion		3799bc	30.6b	12448a	198ab	74a	37.1a	6.3a	224ab	66.7ab	5.6a	71.2b
CDC Boyer		3358c	33.9a	10002b	190ab	54b	32.7a	4.1ab	224ab	75.8a	2.5b	73.9a
Triple Crown		4357a	32.5ab	13458a	184b	75a	34.1a	1.4b	230a	58.3b	1.7b	70.8b
lsd (0.05)		486	2.7	1977	30	17	7.2	3	7	12.60	1.40	1.40
N Rate												
0		4067a	32.9a	12466a	195a	70a	37.0a	3.2b	227a	66.3a	3.3b	72.1a
40		3981a	32.1a	12374a	214a	67a	33.6a	3.7ab	223a	64.6a	3.6ab	71.7a
80		3842a	32.4a	12313a	196a	65a	36.1a	3.8ab	223a	62.6a	4.3a	71.7a
120		3656b	31.9a	11527b	192a	61a	32.1a	4.8a	224a	64.7a	3.8ab	71.8a
lsd (0.05)		210	1.4	649	38	20	5.7	1.1	5	5.4	0.9	0.9
Source of Variation		ANOVA (P>F)										
	df											
Cultivar	3	0.0057	0.0913	0.0133	0.0944	0.0590	0.6796	0.0319	0.0504	0.0352	0.0003	0.0043
N Rate	3	0.0018	0.5439	0.0138	0.7939	0.7569	0.2845	0.0418	0.2981	0.8539	0.2981	0.7706
CxN	9	0.5092	0.8416	0.2066	0.6235	0.5712	0.5880	0.9781	0.5625	0.9891	0.7505	0.7915
CV%		7.4	6	7.3	25.2	39.9	22.4	40.3	2.8	11.4	32.4	1.7

[1] Indicates date of lodging assessment.

a-d means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*CxN refers to cultivar (C) and notrogen rate (N).

Table 4.9 The effect of cultivar and nitrogen fertilizer rate on yield, yield components, and physical milling quality traits of oat cultivars grown at Morden, Manitoba 1998 (high residual N site).

Main Effect	Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No. per square meter	Panicle No. per square meter	Kernels/ panicle	HI%	Lodging(1-9) [1](4.8.98)	Test Wt. (g/0.5L)	Plumps %	Thins %	Groat %
Cultivar											
OT 288	7359a	30.9d	23914a	225a	109a	69.3a	1.4c	250a	70.9b	2.4b	71.8bc
AC Assiniboia	6294b	37.1a	17319b	171b	100a	60.9ab	1.9c	243b	87.6a	1.7b	73.6a
AC Medallion	5774b	34.3bc	16911b	182b	97a	52.0bc	5.4a	236c	76.6b	3.7a	71.0c
CDC Boyer	4409c	36.4ab	12125c	167b	72b	44.4c	4.0b	238bc	84.5a	1.7b	72.7ab
Triple Crown	5592b	32.8cd	17112b	149b	114a	48.7bc	1.9c	242bc	54.6c	2.1b	69.5d
lsd (0.05)	719	2.8	2569	38	19	15.4	1.4	7	6.1	1.1	1.4
N Rate											
0	5859a	35.0a	16960a	176a	98a	61.7a	1.6c	245a	77.8a	1.8c	71.8a
40	5808a	34.5a	17066a	174a	97a	57.4ab	2.5b	243ab	76.4ab	2.1bc	71.7a
80	5936a	34.0a	17877a	182a	100a	52.6b	3.4a	240bc	73.8bc	2.5ab	71.6a
120	5917a	33.9a	17786a	185a	103a	52.1b	4.1a	239c	71.0c	2.9a	71.7a
lsd (0.05)	390	1.1	1304	22	22	8.7	0.8	3	3.3	0.6	0.7

Source of Variation	df	ANOVA (P>F)										
Cultivar	4	0.0001	0.0014	0.0001	0.0065	0.0003	0.0110	0.0002	0.0049	0.0001	0.0078	0.0004
N Rate	3	0.9081	0.1935	0.3727	0.5971	0.8576	0.1260	0.0001	0.0061	0.0002	0.0018	0.8684
CxN	12	0.1936	0.8793	0.2251	0.2331	0.6259	0.9728	0.0186	0.5002	0.0047	0.0340	0.0771
CV%		10.3	5.2	11.6	18.0	20.0	24.2	42.8	2.2	6.8	39.6	1.4

[1] Indicates date of lodging assessment.

a-d means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*CxN refers to cultivar (C) and notrogen rate (N).

Table 4.10 The effect of cultivar and nitrogen fertilizer rate on yield,yield components, and physical milling quality traits of oat cultivars grown at Silverton, Manitoba 1998 (high residual N site).

Main Effect	Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No.	Panicle No.	Kernels/ panicle	HI%	Lodging(1-9) [1](2.9.98)	Test Wt. (g/0.5L)	Plumps	Thins	Groat
			per square meter							%	
Cultivar											
OT 288	4215a	30.7bc	13818a	281a	50a	43.9a	1.1c	256a	76.6a	2.4c	70.2a
AC Assiniboia	2335bc	34.1a	6872d	239b	29c	27.9b	3.8b	227b	74.5a	5.1a	68.7a
AC Medallion	2812b	30.2c	9320b	240b	42b	32.9b	8.0a	230b	67.7b	5.7a	67.9a
CDC Boyer	2188c	31.8b	6878cd	292a	25c	26.8b	7.9a	229b	75.5a	3.4bc	69.6a
Triple Crown	2645bc	30.4bc	8734bc	174c	50a	26.4b	3.8b	234b	59.3c	3.9bc	67.6a
lsd (0.05)	601	1.5	1860	34	6	7.3	2.4	9	4.5	1.1	3.6
N Rate											
0	2791a	31.6a	8921a	249a	39a	30.4a	4.8a	236ab	70.2a	4.2a	68.5a
40	2880a	31.3a	9245a	255a	38a	32.9a	4.8a	232b	71.3a	4.0a	68.8a
80	2839a	31.2a	9155a	231a	39a	32.8a	5.1a	235ab	70.5a	4.1a	68.5a
120	2778a	31.3a	8929a	248a	39a	30.7a	5.1a	237a	70.6a	4.1a	69.2a
lsd (0.05)	364	0.7	1215	35	8	6.1	0.8	4	3.1	0.7	0.8

Source of Variation	df	ANOVA (P>F)										
Cultivar	4	0.0001	0.0007	0.0001	0.0001	0.0001	0.0011	0.0002	0.0001	0.0001	0.0002	0.5671
N Rate	3	0.6668	0.7420	0.6644	0.7616	0.9952	0.7649	0.8094	0.4661	0.7788	0.8207	0.4652
CxN	12	0.8403	0.5079	0.9167	0.0819	0.8500	0.7866	0.2255	0.2893	0.0332	0.0659	0.8720
CV%		20.0	3.6	20.8	21.1	30.5	30.0	23.8	2.7	6.7	28.2	1.9

[1] Indicates date of lodging assessment.

a-d means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*CxN refers to cultivar (C) and notrogen rate (N).

Table 4.11 The effect of cultivar and nitrogen fertilizer rate on yield and yield components and physical milling quality traits of oat cultivars grown at Silverton, Manitoba 1999 (high residual N site).

Main Effect		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No. (per square meter)	Panicle No. (per square meter)	Kernels/ panicle	HI%	Lodging(1-9) [1](29.8.99)	Test Wt. (g/0.5L)	Plumps (%)	Thins (%)	Groat (%)
Cultivar												
OT 288		5777a	31.4c	18461a	332a	59ab	42.3a	1.0c	269a	69.8c	1.5a	71.9ab
AC Assiniboia		5035ab	37.7a	13356c	262bc	52b	38.7a	2.4b	263bc	85.8a	1.2a	73.0a
AC Medallion		4633b	33.2b	13971bc	308ab	46b	36.1ab	3.8a	258c	77.5b	1.8a	71.7abc
CDC Boyer		4314b	33.9b	12647c	304ab	42b	31.9b	4.3a	245d	78.7b	1.7a	71.6bc
Triple Crown		5438a	33.8b	15983b	221c	80a	40.1a	1.6bc	264ab	69.7c	1.3a	70.5c
lsd (0.05)		793	1.2	2243	59	22	6.5	1.0	6	5.3	0.6	1.4
N Rate												
0		4627b	34.2a	13683b	276a	54a	40.4a	1.3b	267a	78.8a	1.3bc	71.6a
40		5267a	35.2a	15090ab	285a	55a	38.6ab	1.5b	265a	78.6a	1.1c	72.0a
80		5212a	33.9ab	15437a	287a	57a	37.4ab	3.5a	255a	75.2ab	1.7ab	71.7a
120		5051ab	32.8b	15324a	296a	58a	34.8b	4.1a	253a	72.6b	1.8a	71.7a
lsd (0.05)		569	1.4	1563	39	8.9	5.3	0.6	6	3.8	0.5	1.2
Source of Variation	df	ANOVA (P>F)										
Cultivar	4	0.0111	0.0001	0.0007	0.0107	0.0193	0.0407	0.0001	0.0001	0.0001	0.2578	0.0221
N Rate	3	0.1134	0.0118	0.1017	0.7828	0.6731	0.1961	0.0001	0.0001	0.0054	0.0162	0.9004
CxN	12	0.2665	0.0075	0.5809	0.8873	0.5945	0.8373	0.0001	0.0004	0.0047	0.0922	0.0057
CV%		17.7	6.4	16.5	21.5	25.0	22.1	38.8	3.6	7.9	49.8	2.6

[1] Indicates date of lodging assessment.

a-d means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

*CxN refers to cultivar (C) and notrogen rate (N).

The conventional tall cultivars performed similarly for grain yield with the exception of CDC Boyer which was the lowest yielding at all four sites (Tables 4.8 to 4.11), similar to results at the low N site years. Lower yield for CDC Boyer relative to other tall cultivars coincided with lower kernel numbers per square meter and significantly fewer kernels per panicle (Tables 4.8 to 4.11). CDC Boyer appeared to be sink limited for grain yield, however it consistently demonstrated high kernel weights, and correspondingly high groat and percent plump kernel percentages. This illustrates the difficulty in balancing increased grain yields with higher N rates and milling quality as seen at the low N sites. In the case of CDC Boyer, however the relationship was opposite to that observed in OT 288; CDC Boyer produced fewer but larger kernels, while OT 288 produces more but smaller kernels.

OT 288 had higher harvest indexes than the tall cultivars at the three high N sites at which it was evaluated (Tables 4.9 to 4.11). It should be noted that harvest indexes at Morden in 1998 were unusually high, with values ranging from 44% up to 69%. Although studies in Finland have found optimum harvest indexes at close to 55% and some as high as 69% (Peltonen-Sainio 1991), it is more likely that the harvested dry matter weights were somehow affected by leaf loss prior to harvesting, distorting harvest indexes. Therefore their use in supporting OT 288's yield superiority could be misleading.

4.4.1.2 Physical Milling Quality Characteristics

Nitrogen had no significant effect on milling quality parameters at Elm Creek and Silverton in 1998 (Tables 4.8 and 4.10). Milling quality at both sites was generally poor, with mean test weights of 224 g/0.5 L and 235 g/0.5 L respectively, and percent plump kernels of 64.5 and 70.1 respectively. These results indicate poor potential for milling quality oat under high residual N sites. Milling grade oat should have a minimum test weight of 245 g/0.5 L and approximately 90% plump kernels (Ganssmann and Vorwerck, 1995).

At Morden 1998 and Silverton 1999, where quality potential was high relative to Elm Creek and Silverton in 1998, added N significantly reduced quality parameters. At Silverton in 1999, this may have been due to a negative affect of N on kernel weight ($p<0.05$). At Morden 1998, the number of kernels per panicle was relatively high (as high as 100 kernels per panicle vs. 58 kernels per panicle at Silverton 1999), possibly due to a lower number of panicles per m^2. This may have resulted in a distribution of dry matter over a greater number of kernels and therefore a greater number of smaller kernels. At both locations, test weight and percent plump kernels were decreased with added N while percent thin kernels were increased. Groat percentage was unaffected by increasing N fertilizer. A cultivar x N interaction was observed for groat percentage at both locations, with inconsistent responses. Significant cultivar x N interaction effects were observed for percent plump and thin kernels at Silverton 1998 and 1999 and Morden 1998 but were also inconsistent.

These results reflect the difficulty of balancing N levels for both grain yield and milling quality. Although the higher N levels did not significantly reduce yield, they did increase kernel numbers, possibly due to the production of greater numbers of secondary florets, therefore resulting in poorer milling quality. In terms of milling quality, none of the five cultivars evaluated resulted in high milling quality across all excessive N conditions.

Cultivar effects were significant for test weight and percent plump kernels in all four site years (Tables 4.8 to 4.11). At the three of four sites where OT 288 was evaluated, it resulted in higher test weights than the tall cultivars. Although the test weights for OT 288 at these sites would be considered milling grade, this high test weight was again the result of a reduction in the number of plump kernels, resulting in a greater packing efficiency. This mechanism of achieving high test weight is also illustrated in the consistently low kernel weights found in OT 288 at these three sites (Tables 4.9 to 4.11). Triple Crown resulted in consistently low levels of plump kernels. Cultivar effects were significant for groat percentage at Elm Creek 1998, Morden 1998, and Silverton 1999 (Tables 4.8, 4.9, 4.11); none of the cultivars was consistently the highest or lowest for groat percentage across the three sites.

Excessive N levels can result in reduced milling quality but not necessarily reduced grain yields. Results from these high residual N sites demonstrate the importance of monitoring soil N levels to determine actual soil N supply prior to fertilizer recommendations and application (Soper et al., 1971). These fields did not require additional N fertilizer to produce a high yielding oat crop. Often producers do not have an accurate estimate of available N at seeding, demonstrated by the two Silverton sites located on farmers' fields. The high residual N locations resulted in the wasted cost of unnecessary fertilizer and the possibility of poorer milling quality when quality potential was high. Excess N would also contribute substantial amounts of leachable N. Such excessive use of N fertilizer is unsustainable and contributes to environmental problems, including ground water contamination. Errors in estimating available N supply could be prevented with better field records and soil testing.

4.4.1.3 Lodging

Effects of cultivar on lodging score (prior to harvest) were significant at all high N sites (Table 4.8.to 4.11). In all four site years, AC Medallion had the highest lodging scores, followed by CDC Boyer. OT 288 was not evaluated in Elm Creek in 1998. OT 288 had significantly lower lodging scores than the other tall cultivars in Silverton in 1998 and 1999 (Tables 4.10 and 4.11). In Morden 1998, OT 288, AC Assiniboia and Triple Crown all resulted in lower lodging scores than AC Medallion and CDC Boyer (Table 4.9).

Nitrogen effects were significant for lodging score at Morden in 1998 and Silverton in 1999 where the 80 and 120 kg/ha N rates resulted in increased lodging. At these same sites, C x N effects were significant for lodging (Figure 4.7). In both cases the lodging scores of AC Medallion and CDC Boyer increased with increasing N levels while OT 288's lodging score remained low.

Marshall et al. (1987) suggested the yield advantages of semidwarf oat lie in their protection of yield through the prevention of lodging. The prevention of lodging results in uninhibited assimilate flow, found in an upright crop, and/or less grain loss during harvesting due to an upright crop. Similar to the previous study (refer to Section 3) the higher yields of OT 288 were associated with greater panicle densities and kernel

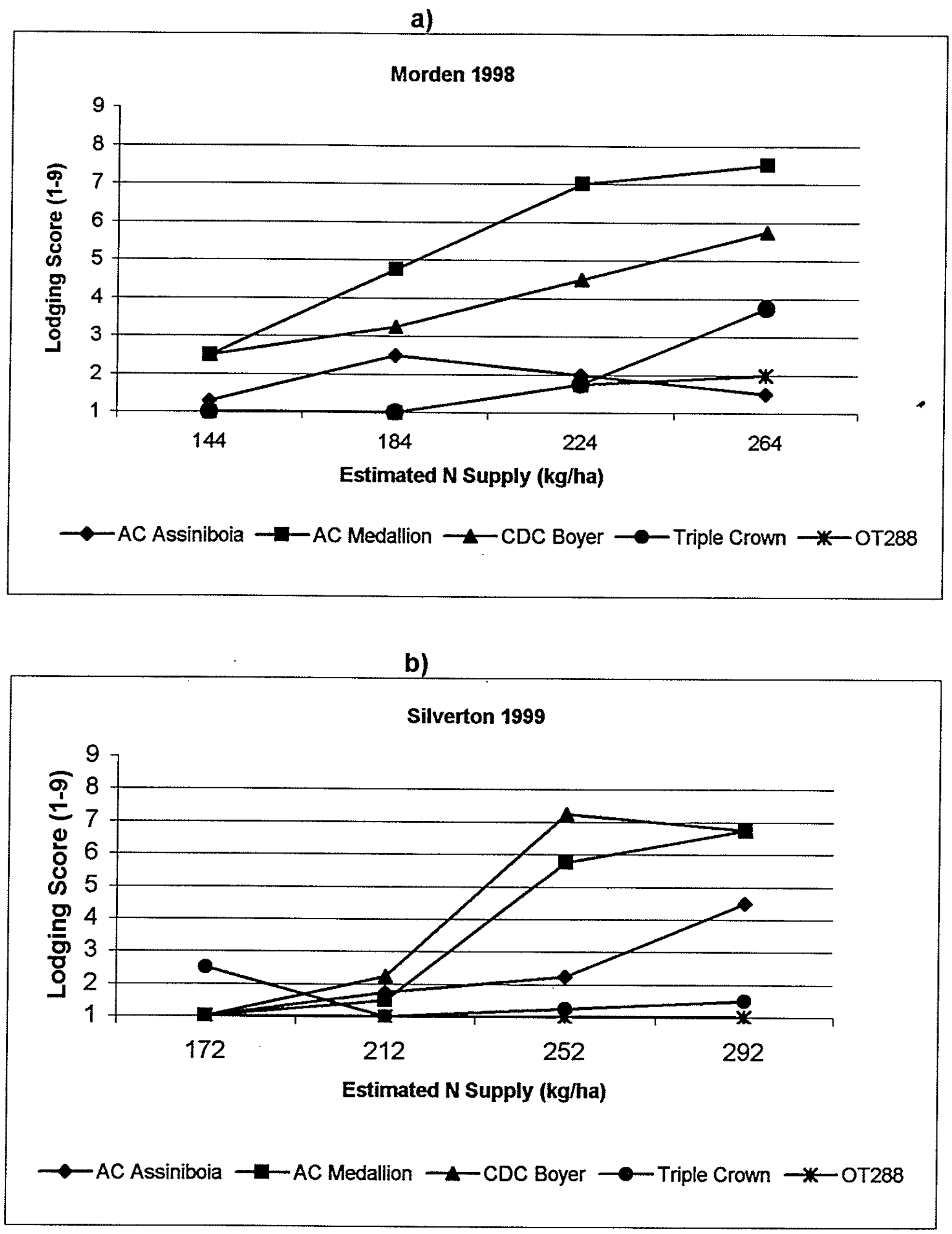

Figure 4.7 Mean lodging scores at a) Morden 1998 and b) Silverton 1999; locations where cultivar x nitrogen interactions were observed.

numbers, i.e greater sink size determined preanthesis prior to lodging. Therefore the yield superiority of OT 288 is difficult to attribute to lodging "resistance". Also, contrary to this theory is the fact that CDC Boyer, which resulted in some of the highest lodging scores, also resulted in some of the highest kernel weights. This suggests that post anthesis effects, i.e kernel mass, on yield do not always result from lodging and that a high quality cultivar such as CDC Boyer can maintain quality despite lodging. Timing of lodging is also an important factor in determining the impact of lodging, however this was not evaluated in the present study.

Grain yield under high N conditions was not improved with additional N, but average grain yields among sites was not substantially different from the grain yields under the low N sites. Under these conditions OT 288 stood out as the superior yielding cultivar due to its increased sink size as seen in the previous experiment. AC Assiniboia and Triple Crown had less lodging under high N conditions than CDC Boyer and AC Medallion. Therefore AC Assiniboia and Triple Crown could prevent grain loss during harvesting and improve ease of harvesting. Excessive N cannot only result in poorer quality it can also cause additional financial losses through increased lodging and loss of grain during harvesting.

4.5 Summary and Conclusions

Grain yield responses to N fertilizer were dependent on residual soil test N levels prior to seeding. Sites with high levels of residual N, >100 kg/ha nitrate N, did not respond to N fertilizer, and at one location responded negatively. Positive responses to N fertilizer were observed at low residual N sites; where indigenous N was equal to or less than 36 kg/ha nitrate N. Lower levels of residual N revealed C x N interaction effects; CDC Boyer was relatively unresponsive to N fertilizer at low residual N sites, AC Assiniboia, Triple Crown, and AC Medallion responded positively for grain yield up to an optimal level of approximately 100 kg/ha N. Beyond the optimal level, the yield of AC Medallion decreased more sharply than Triple Crown, while the yield of AC Assiniboia was maintained. The semidwarf OT 288 had a unique N response curve; N responses occurred up to levels of 130 kg/ha N, and grain yields were significantly higher across all N levels compared to the tall cultivars. This suggests a higher yield potential with the release of semidwarf oat cultivars in the future as a result of an increased sink size achieved through greater panicle production per m^2 and the corresponding increase in kernel number per m^2.

This study did not reveal any consistent, positive cultivar x N interactions for milling quality, i.e. any interaction effects that could be taken advantage of to increase milling quality. As N could not effectively be used to consistently improve quality with any of the cultivars evaluated, a cultivar was also not identified and being better suited to low N conditions in terms of milling quality. Under low N conditions cultivar effects for milling quality were evident; Triple Crown performed erratically for test weight, kernel plumpness and percent groat, suggesting that Triple Crown may not be well suited to

Manitoba growing conditions. AC Assiniboia, on the other hand, maintained consistently high quality across N rates, suggesting that it is the better choice for Manitoba growing conditions. Although CDC Boyer displayed superior milling quality, i.e. high levels of plump kernels and high groat percentage, it consistently resulted in lower yields and did not respond to N fertilizer. Similar to the previous study, OT 288 displayed extremely high yield potential, however the milling quality characteristics were inferior to AC Assiniboia.

None of the tall cultivars evaluated, under high N conditions, responded positively to additional N for yield or milling quality. Therefore none could be recommended for improved performance under high N conditions although, in terms of preventing lodging and yield loss during harvest, AC Assiniboia, and Triple Crown would be better suited to these environments. Cultivar x N interactions revealed AC Medallion and CDC Boyer to have high levels of lodging under high N conditions. Therefore producers can minimize lodging with these cultivars through improved monitoring of soil N levels and applying N fertilizer at the levels recommended by this study.

5. SUMMARY AND CONCLUSIONS

1. Valuable information on seeding dates and seeding rates for oat in Manitoba has resulted from this research. Producers can ensure the most profitable oat crop, with high yields and milling grades. This can be achieved through cultivar selection and early seeding with moderate (300 seeds/m^2) seeding rates.

2. When seeding delays are unavoidable, significant yield reductions may not be suffered with the cultivars evaluated, however reduced milling quality may occur. AC Assiniboia resulted in less negative effects on milling quality with late seeding than AC Medallion. This makes AC Assiniboia an excellent choice for situations where late seeding is desirable, i.e. wild oat control, or unavoidable, i.e. under wet seeding conditions.

3. The practice of increasing seeding rates with delayed seeding to improve yield or quality did not provide any agronomic or quality benefit in this study. This was due to the inverse relationship between panicle density and kernels per panicle in response to increased seeding rate; increased seeding rates resulted in greater panicle numbers but fewer kernels per panicle.

4. The semidwarf OT 288 had higher grain yields than both AC Assiniboia and AC Medallion. This increased yield was due to an increased productivity achieved through greater panicle density and kernels per panicle, i.e. increasing sink size. OT

288 responded similarly to the tall cultivars in terms of optimum seeding dates, and seeding rates for grain yield, illustrating that it did not require differential management practices than taller cultivars.

5. The milling quality potential of OT 288 was limited by its low kernel mass, the result of dry matter distribution over a greater sink size. This low kernel size negatively affected related quality traits such as percent plump kernels and groat percentage.

6. Effects of seeding date and seeding rate on lodging were inconsistent. Quality reductions with delayed seeding could not be directly attributed to lodging as AC Medallion and AC Assiniboia had greater lodging than OT 288, but had higher kernel weights. Quality reductions with delayed seeding could be attributed to a reduced time for grain filling and assimilate production or unfavorable conditions negatively affecting kernel fill.

7. A total estimated N supply (residual plus fertilizer N) of approximately 100 kg N/ha was found to be the optimal level for grain yield benefits for AC Assiniboia, Triple Crown, and AC Medallion. CDC Boyer was relatively unresponsive to N fertilization; its optimal level was found to be approximately 90 kg N/ha. OT 288 was proven to be more responsive to N fertilization than all of the tall cultivars, with its optimal N level for grain yield at approximately 120 kg N/ha estimated N supply.

8. Cultivar x N interactions for grain yield found that yields of Triple Crown, CDC Boyer and AC Medallion were reduced beyond the optimal N level while the yields of AC Assiniboia and OT 288 were maintained. This suggests that N over-fertilization can be more detrimental to the yields of Triple Crown, AC Medallion, and CDC Boyer.

9. The increased responsiveness of OT 288 to N fertilization was due to its improved productivity, achieved through greater panicle density with increasing N while maintaining the number of kernels per panicle, both of which increased sink size.

10. Evaluating newly released cultivars for N response is necessary in order to ensure efficient and environmentally responsible application of N fertilizer. In all but one high N site, the cultivars evaluated did not result in yield losses with additional N fertilizer however there was no yield advantage to the additional N. Negative affects of N were seen in reduced milling quality in some cases and increased lodging especially with the cultivars CDC Boyer and AC Medallion. This illustrates the critical nature of monitoring available soil N levels to ensure high yielding and high quality oat.

11. Strategies that reduced lodging in the present study included selecting AC Assiniboia over AC Medallion and CDC Boyer, monitoring of soil N levels, and application of each cultivars optimal N rate. Excessive N rates will increase lodging especially with the cultivars AC Medallion and CDC Boyer.

12. Plant breeders, plant pathologists and Manitoba oat breeding programs are necessary for the delivery of cultivars that perform consistently across a diverse range of environments. AC Assiniboia, one of two cultivars from the Manitoba breeding program, resulted in consistent yield and quality across a range of environments, and agronomic practices. The Finnish cultivar Triple Crown responded erratically for milling quality across the environments studied. Up to date disease resistance makes it possible for cultivars like AC Assiniboia to not lose significant yield with delayed seeding.

6. GENERAL DISCUSSION

Although Manitoba has become one of North America's largest milling oat producing regions, producers have been relying on out of date agronomic information based on obsolete oat cultivars in other parts of North America. For this reason as well as the recent advances in semidwarf oat genotypes, up to date and accurate agronomic information was needed for Manitoba producers. This study determined valuable management practices for oat in Manitoba, thus ensuring the most profitable oat crop with high yields and milling grades. In addition, an unreleased semidwarf oat line was evaluated in comparison to traditional tall oat cultivars in order to determine whether differential management was required.

The present study determined that early seeding and cultivar choice were the most important determinants of milling quality. AC Assiniboia's superior performance with late seeding can be an important tool that producers can take advantage of when seeding delays cannot be avoided. Delayed seeding did not significantly reduce grain yield in the present study however this is not a recommended practice. But when necessary for weed control delayed seeding may not significantly reduce grain yields.

The lack of response to higher seeding rates for both yield and quality demonstrated that when higher seeding rates are needed for example, weeds with no chemical control, yield and quality reductions would not result. In 1998, Glenlea had a weed infestation, which may have impacted competition for nutrients and moisture and therefore might have led to incomplete grain filling and therefore the lower kernel weights and low percentage plump kernels observed at this site. A more thorough examination of varying seeding rates and kernel size distribution could help to determine the ideal seeding rate to achieve greater kernel fill under high weed competition. A more in depth evaluation of seeding rate and kernel size distribution and the breakdown in secondary and tertiary floret production and consistency of kernel size distribution could also be useful in determining the importance of seeding rate in terms of physical grain quality.

It seems logical that a greater tiller density might affect lodging, however in this study, increasing seeding rates were not correlated to lodging. The evaluation of lodging in the present study was very limited. A more thorough evaluation of seeding rate and its impact on lodging should include a greater separation between experimental plots, to prevent plots from leaning onto one another.

It is thought that registration of semidwarf oat cultivars would result in reduced lodging incidence and increased responsiveness to N fertilization. OT 288 had less lodging and was more responsive to N additions than traditional tall cultivars. OT 288 responded for grain yield up to 120 kg/ha N while yield of the tall cultivars leveled off at approximately 100 kg/ha N. This increased grain yield was achieved due to an increased kernel number due to a greater tiller and panicle density in response to increasing N levels. As kernel number was determined preanthesis it was difficult to attribute the increased grain yield to a reduction in lodging. However the evaluation of lodging in this study was extremely limited. A more thorough evaluation of lodging would determine timing of lodging, whether lodging was due to extreme weather occurrences and the specific evaluation of areas of the plot affected by lodging.

Although it was difficult to develop direct relationships between lodging and quality there is no argument that the prevention of lodging can substantially improve the ease of harvesting as well as the additional loss of grain during harvesting. For these reasons alone, the future release of improved semidwarf cultivars will be an improvement to current practices. As the release of AC Ronald is relatively recent, producers using the traditional tall cultivars can prevent unnecessary lodging with proper N management and applying only levels of N that the crop will use. Based on this study, 100 kg N/ha total estimated supply could limit lodging. And the avoidance of AC Medallion and CDC Boyer can provide additional benefits.

OT 288's potential for registration was limited by its poor physical milling quality. Although high test weights were observed, they were achieved due to the packing of a larger number of smaller kernels into the hectoliter volume container. Additional quality analysis revealed poor plump and thin kernel, and groat percentages. These quality limitations could not be overcome with any of the management tools used in this study.

The potential of semi dwarf oat cultivars is evident in this study. Genetic improvements could help to overcome the difficultly in achieving the ideal balance between kernel number and kernel weight. The inverse relationship between kernel number and kernel weight illustrates how difficult the challenge is in balancing yield and quality. OT 288 resulted in kernel numbers up to 14000 per square meter vs. approximately 8000 per square meter for the tall cultivars. Although this high kernel number resulted in higher grain yields, milling quality suffered. Future semidwarf cultivars could result in a better compromise between yield and quality, with slightly lower kernel numbers, still increasing yield without such a negative impact on kernel size.

Whether or not the yield and lodging benefits seen in OT 288 can be attributed to the semi dwarfing gene or some other component of its genetics remains to be seen. This question could be addressed through the development of isogenic lines, however these have not yet been developed.

The argument was made in the present study, that test weight might not be the most reliable indicator of milling quality. A limited number of cultivars were evaluated in this study; therefore the evaluation of other registered cultivars is needed and similar correlations conducted to confirm these results.

CDC Boyer's low yields but corresponding large kernel size revealed an additional question, not addressed here. Ideally the producer would like to achieve the highest quality and the highest grain yield. Due to the inverse relationship between kernel number and kernel weight achieving the ideal balance between the two is difficult. Therefore the issue of the economics of producing strictly for high yield regardless of quality versus producing strictly for high quality i.e. CDC Boyer regardless of grain yield exists. An evaluation of the economics of both situations could be a useful tool for producers.

As have other studies in the past, this study demonstrates the need to evaluate newly released oat cultivars under Manitoba growing conditions in order to determine ideal management practices. Although the cultivars AC Assiniboia, AC Medallion and CDC Boyer were developed in Western Canada and were similar in height and disease resistance, each revealed unique responses to N management as well as lodging. The cultivars AC Medallion and CDC Boyer were also revealed to have more detrimental effects when the optimal N level was exceeded.

Increasing N fertilizer levels did not improve milling quality. To the contrary higher N levels can result in reduced quality due to the greater number of kernels produced with increasing N, and therefore the distribution of assimilates over a greater number of kernels resulting in smaller, less filled kernels. In most cases the latter could be avoided with the use of the optimal N level for each cultivar.

The cultivars evaluated in this study were developed in a range of locations; CDC Boyer in Saskatchewan, Triple Crown in Europe, and AC Assiniboia and AC Medallion in Manitoba. CDC Boyer exhibited poor yield across locations and N conditions, while Triple Crown resulted in extremely inconsistent performance across locations. AC Assiniboia was determined to be extremely consistent in terms of yield and quality over a range of management practices, some of which were less than ideal. These results demonstrate the necessity of oat breeding programs in regions where the cultivars will be grown. The present study confirms the excellent efforts of Manitoba's oat breeding programs but also confirms the need for additional funding for ongoing agronomic management studies to provide producers with the tools they need to achieve superior results with the newer cultivars.

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8. APPENDIX A

8.1 LIST OF TABLES IN APPENDIX A

Appendix A1: ANOVA model used in split-split plot statistical analysis

Main Effect & Interactions	Error Term
Block	Block x Seeding Date
Seeding Date	
Cultivar	Block x Cultivar (Seeding Date)
Seeding Date x Cultivar	
Seeding Rate	Block x Seeding Rate (Cultivar x Seeding Date)
Seeding Date x Seeding Rate	
Cultivar x Seeding Rate	
Seeding Date x Cultivar x Seeding Rate	

Appendix A.2: Codema Procedure and Settings

Air holes = ~7/16 in.

Blast gate = ~1.5 cm.

Air pressure = 104 psi.

After fan and air pressure has been turned on, place seed sample into hopper with knife gate closed (sample size 70 g). Open knife gate slowly to drop seed into chamber. Let seed circulate through the system for one minute once all seed has been dropped into the chamber. When the time has been reached, move the lever into the discharge position to move groats and hulls into appropriate canisters. Run in discharge position for 10 seconds. Turn off the air switch, followed by the fan switch. Clean out canisters and weigh.

Appendix A.3. Mean squares yield and yield components at four locations in Manitoba (Winnipeg, Carman, Morden 1998-1999).

		Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No.	Tiller No.	Panicle No.	Kernels/ Panicle	HI %
				per square meter				
					Morden 1998			
	df							
Date	2	307770	67**	1244527	91810	126	43	64
Cultivar	2	3886448***	357***	95838263***	106798**	13121***	309*	336**
Rate	1	246336	2.88	471932	123774***	24449***	2043**	25
DatexCutivar	4	678772*	29*	4877193	31078	457	92	20
DatexRate	2	326573	0.75	2008871	22525	1107	75	49
CultivarxRate	2	574340	2.46	4194069	3271	809	77	16
DxCxR	4	109003	6.76	1621910	10153	158	17	25
					Winnipeg 1998			
	df							
Date	2	269709	96**	6349719	61183	15452*	716	322
Cultivar	2	5211220***	351***	117335912***	78856	9333*	4340	378*
Rate	1	10296	1.93	9716	404850**	7453	4704	0.34
DatexCutivar	4	441664	9.78	2603677	23699	1039	2406	53
DatexRate	2	86804	1.86	1605108	21182	5734	1408	35
CultivarxRate	2	198637	4.47	1955086	17635	1664	1067	21
DxCxR	4	124133	2.37	1797499	22581	2743	1881	41
					Carman 1999			
	df							
Date	2	372751	68*	18178432*	89193**	9657**	923**	55
Cultivar	2	5874164***	240***	119365030***	30275***	21138***	446**	412***
Rate	2	210465	0.18	1151033	9746**	12345***	472***	22
DatexCutivar	4	166373	10*	56220	1384	1296	26	18
DatexRate	4	66544	0.31	625535	1627	118	27	7.83
CultivarxRate	4	101178	5.07*	449128	711	441	28	16
DxCxR	8	104297	1.22	974052	1321	771	37	23
					Winnipeg 1999			
	df							
Date	2	1298832*	2.37	10830979	215117***	51874*	2443*	717*
Cultivar	2	5464260***	513***	225423251***	50763***	16302*	1332*	451***
Rate	2	20414	4.26*	1714191	11671**	10691**	795**	14
DatexCutivar	4	108795	6.17*	2759631	11497*	740	259	20
DatexRate	4	234730*	0.54	1825335	1147	2001	219	11
CultivarxRate	4	73189	1.66	1026939	3242	1222	189	57*
DxCxR	8	81723	1.42	969494	1710	218	24	22

*, **, *** Significant at the .05, .01, .0001 probability levels, respectively

Appendix A.4. Mean squares for lodging and quality at four locations in Manitoba (Winnipeg, Carman, Morden 1998-1999).

		Lodging (scale 1-9)	Test Wt. (g/0.51)	Groat	Plumps	Thins
					%	
				Morden 1998		
	df					
Date	2	27*	1162**	69.6**	1286*	27***
Cultivar	2	79***	599***	40***	1533***	26***
Rate	1	5.2**	170**	12**	17	2.10*
DatexCutivar	4	2.6	125**	8.7**	131**	9.5***
DatexRate	2	0.3	24	2.8	49	0.38
CultivarxRate	2	0.5	12	0.1	14	0.18
DxCxR	4	0.3	29	2.5	75**	0.83
				Winnipeg 1998		
	df					
Date	2	143**	569	60*	4008**	47**
Cultivar	2	5.5	293**	39***	1333***	30***
Rate	1	0.1	52	1.05	9.39	0.3
DatexCutivar	4	8.2	87	1.24	115	3.99
DatexRate	2	0	12	1	100*	0.69
CultivarxRate	2	0.3	4.51	0.58	39	3.47
DxCxR	4	0.2	19	1.05	15	2.08
				Carman 1999		
	df					
Date	2	13.8	1684***	14	392	2.07
Cultivar	2	168***	160**	91***	4604***	4.24***
Rate	2	7.9**	44*	1.15	77	0.28
DatexCutivar	4	8	14	6.74*	270*	0.86*
DatexRate	4	0.6	9.91	0.49	26	0.06
CultivarxRate	4	5.4***	19	0.23	27	0.11
DxCxR	8	0.7	7.59	0.47	32	0.07
				Winnipeg 1999		
	df					
Date	2	95*	1861***	52***	828***	25**
Cultivar	2	34**	345***	74***	4141***	7.18***
Rate	2	0.3	33*	6.02***	165***	4.51***
DatexCutivar	4	27**	43	7.93*	166**	2.66*
DatexRate	4	0.3	11	0.7	32*	0.22
CultivarxRate	4	0.1	4.45	1.48*	45*	0.26
DxCxR	8	0.1	8.95	1.07*	27*	0.46

*, **, *** Significant at the .05, .01, .0001 probability levels, respectively

Appendix A.6. The Effect of Seeding date, cultivar, and seeding rate on field measurements, Morden 1998.

Main Effect		Plant Counts	Dry Matter Anthesis	Dry Matter Maturity	Plant Height Maturity (cm)
		per square meter			
Seeding Date					
Early		153b	593b	977a	111a
Mid		158b	720a	909a	107ab
Late		182a	710a	925a	100b
lsd (0.05)		20	67	163	24
Cultivar					
OT 288		189a	630b	931a	86c
AC Assiniboia		163b	723a	971a	112b
AC Medallion		141c	666ab	910a	118a
lsd (0.05)		18	61	83	9
Seeding Rate					
200		110b	650b	923a	106a
400		217a	697a	952a	106a
lsd (0.05)		14	46	69	1.7
Source of Variation	df				
Date	2	0.0259	0.0056	0.6162	0.0765
Cultivar	2	0.0001	0.0293	0.3143	0.0001
Rate	1	0.0001	0.0721	0.6296	0.3458
DatexCutivar	4	0.4243	0.8763	0.2066	0.0740
DatexRate	2	0.6888	0.0536	0.9489	0.0338
CultivarxRate	2	0.8583	0.6815	0.7061	0.1775
DxCxR	4	0.1210	0.2135	0.5076	0.4029

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

Appendix A.5. The Effect of Seeding date, cultivar, and seeding rate on field measurements, Winnipeg 1998.

Main Effect		Plant Counts	Dry Matter Anthesis	Dry Matter Maturity	Plant Height Maturity (cm)
		per square meter			
Seeding Date					
Early		171a	555b	979a	110a
Mid		147b	760a	1057a	112a
Late		168a	692ab	1138a	111a
lsd (0.05)		20	167	255	11
Cultivar					
OT 288		182a	680a	1075a	92b
AC Assiniboia		150b	656a	1056a	120a
AC Medallion		150b	670a	1042a	121a
lsd (0.05)		22	59	83	2
Seeding Rate					
200		116b	654a	1078a	111a
400		209a	684a	1037a	110a
lsd (0.05)		20	45	67	2
Source of Variation	df				
Date	2	0.0516	0.0597	0.3741	0.9556
Cultivar	2	0.0138	0.6912	0.6989	0.0001
Rate	1	0.0001	0.1923	0.2166	0.2279
DatexCutivar	4	0.2277	0.2133	0.0974	0.2189
DatexRate	2	0.5566	0.0981	0.2537	0.0190
CultivarxRate	2	0.9076	0.1324	0.7511	0.9354
DxCxR	4	0.6618	0.7658	0.6035	0.3950

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

Appendix A.7. The Effect of Seeding date, cultivar, and seeding rate on field measurements, Carman 1999.

Main Effect		Plant Counts	Dry Matter Anthesis	Dry Matter Maturity	Plant Height Maturity (cm)
		per square meter			
Seeding Date					
Early		205a	747a	1176a	110a
Mid		177b	628b	1124ab	108a
Late		197ab	786a	1081b	107a
lsd (0.05)		21	53	76	11
Cultivar					
OT 288		193ab	712a	1136a	89b
AC Assiniboia		184b	714a	1111a	117a
AC Medallion		202a	733a	1134a	119a
lsd (0.05)		11	44	47	2.5
Seeding Rate					
200		138c	689b	1126a	110a
300		191b	731a	1124a	108a
400		250a	738a	1131a	108a
lsd (0.05)		13	23	47	1.9
Source of Variation					
	df				
Date	2	0.0460	0.0009	0.0720	0.7786
Cultivar	2	0.0140	0.5430	0.4203	0.0001
Rate	2	0.0001	0.0004	0.9612	0.0722
DatexCutivar	4	0.0910	0.8891	0.1310	0.2152
DatexRate	4	0.0549	0.4046	0.4142	0.5549
CultivarxRate	4	0.9665	0.0977	0.9835	0.0329
DxCxR	8	0.5474	0.3194	0.5884	0.5311

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

Appendix A.8 The Effect of Seeding date, cultivar, and seeding rate on field measurements, Winnipeg 1999.

Main Effect	Plant Counts	Dry Matter Anthesis	Dry Matter Maturity	Plant Height Maturity (cm)
	per square meter			
Seeding Date				
Early	171a	570c	1092a	110a
Mid	177a	732b	1064a	111a
Late	172a	883a	856b	106b
lsd (0.05)	21	47	57	1.8
Cultivar				
OT 288	178ab	706b	1016a	89c
AC Assiniboia	159b	710b	987a	118b
AC Medallion	184a	770a	1009a	120a
lsd (0.05)	22	42	62	1.1
Seeding Rate				
200	119c	711a	998a	109a
300	180b	714a	1013a	109a
400	222a	760a	1002a	108a
lsd (0.05)	16	67	49	1.2

Source of Variation	df				
Date	2	0.7492	0.0001	0.0001	0.0011
Cultivar	2	0.0673	0.0074	0.6084	0.0001
Rate	2	0.0001	0.2693	0.8209	0.3486
DatexCutivar	4	0.3337	0.1686	0.5350	0.0001
DatexRate	4	0.2799	0.8765	0.9810	0.3907
CultivarxRate	4	0.1340	0.6781	0.1400	0.5712
DxCxR	8	0.4867	0.2079	0.6726	0.7517

a-c means followed by the same letter are not significantly different according to fisher's lsd test (p>0.05).

9. APPENDIX B

9.1 LIST OF TABLES IN APPENDIX B

Appendix B1: ANOVA model used in split-split plot statistical analysis

Main Effect & Interactions	Error Term
Block	Block x Cultivar
Cultivar	
Nitrogen Fertility	Block x Nitrogen Fertility (Cultivar)
Cultivar x Nitrogen Fertility	

Appendix B2: Mean squares for oat yield, yield components, and physical quality characteristics (1998-1999)

	df	Yield (kg/ha)	Kernel Wt. (mg/kernel)	Kernel No. per square meter	Panicle No. per square meter	Kernels/ Panicle	HI%	Test Wt. (g/0.5 l)	Plumps %	Thins %	Groat Yield %
Elm Creek 1998											
C	3	2986510**	32	37534936*	3594	1537	39	292	1063*	57**	29**
N	3	510744**	3	3237398*	862	273	80	52	14	2	1
CXN	9	77052	2	1145311	1993	592	51	35	12	1	1
Glenlea 1998											
C	4	6353762**	177***	114193991	5009	1367**	623	2947***	5253***	170**	127***
N	3	7111135***	38**	96633518***	3484**	2467**	423	342***	1496***	150***	1
CXN	12	827448*	9	9201962**	928	296	97	58	40	15	2
Morden 1998											
C	4	18321406***	111**	282702641***	6417**	4910	1553*	519**	2708***	11**	38**
N	3	67299	5.2	4412350	659	100	367	133**	204**	4.94*	0.3
CXN	12	525022	1.7	5591949	1402	322	64	27	75**	1.78*	2
Silverton 1998											
C	4	10135743***	41**	126166870***	31382***	1972***	840	2113***	836***	27**	16
N	3	167065	1	1873134	1050	3	34	35	8.2	0.4	1.5
CXN	12	186492	1	1690079	4871	81	57	51	48*	3	0.94
Carman 1999											
C	4	3925231***	108***	44267259***	18628***	789**	215**	123	1839***	5***	70***
N	3	7734326***	13**	57810864***	6469**	594***	21	326***	84	3**	9***
CXN	12	425155**	9***	3613196**	4349**	95	43	27	98**	2**	2**
Silverton 1999											
C	4	5578482*	87***	88687062**	30999*	3572*	261*	1273***	727***	1.02	13*
N	3	1678031	20*	13223795	1357	100	113	1014***	174*	2.08*	0.66
CXN	12	1017889	13**	5247597	1983	166	41	345**	105*	0.94	9.65**
Winnipeg 1999											
C	4	3823958**	209**	45522342**	21625**	1406**	523	419	8296***	6.6**	240
N	3	36926778***	2.6	330471322***	39207***	2367***	414	283**	69	1.1	90
CXN	12	2350754***	2.9	19066156***	3927***	439*	265	89	71*	0.4	110

*, **, *** Significant at the .05, .01, .0001 probability levels, respectively